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SLUDGE DISPOSAL ON LAND

ITS FUTURE IN BRITISH COLUMBIA

a Technology Transfer Seminar

held at

The Hotel Vancouver

Vancouver British Columbia

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A Technology Transfer Seminar sponsored jointly by
the B. C. Water and Waste Association and the Province
of British Columbia, Ministry of Environment
held in the Waddington Room, Hotel Vancouver
Vancouver, British Columbia.
April 16, 1980

SLUDGE DISPOSAL ON LAND: ITS FUTURE IN BRITISH COLUMBIA

Historical Background to Sludge Disposal

- J. E. Dew-Jones, P. Eng., Manager - Resource Recovery Section, Waste Management Branch, British Columbia Ministry of Environment

Sludge Quantities from Waste Treatment Processes

- N. W. Schmidtke and H. W. Campbell, Wastewater Technology Centre, Burlington, Ontario, Environment Canada

Sludge Application to Land - Health Implications

- J. M. Robinson M. B. FRCP(C), Department of Health Care and Epidemiology, Faculty of Medicine, University of British Columbia, Vancouver, British Columbia

Lysimeter and Field Studies on Land Application of Wastewater Sludges

- M. D. Webber, Wastewater Technology Centre, Environmental Protection Service, Environment Canada, Burlington, Ontario
- Y. K. Soon and T. E. Bates, Department of Land Resource Science, University of Guelph, Guelph, Ontario

The Future of Sludge Regulation in British Columbia

- R. D. Wetter, P. Eng., Resource Recovery Section, Waste Management Branch, British Columbia Ministry of Environment

Agricultural Aspects of Sludge Application to Cropland

- R. A. Bertrand, Director - Soils Branch, British Columbia Ministry of Agriculture

Composting of Raw Sludge With Forest Industry Waste

- G. M. Steven, C.E.T., Pollution Control Superintendent, City of Kelowna, British Columbia

A Presentation of the Municipality of Metropolitan Seattle (Metro) Sludge Utilization Research

- Ralph S. Domenowske, Research and Special Projects Coordinator, Municipality of Metropolitan Seattle, Seattle, Washington, U.S.A.

HISTORICAL BACKGROUND TO SLUDGE DISPOSAL

BY

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In considering how best to ensure that a seminar like this takes off to a flying start, we must admit that the subject matter does not make the task any easier. Indeed the word "sludge" seems redolant of all that most people don't want to have anything to do with although our mutual responsibilities in the matter, or for the matter, are evident. Perhaps we could attract bigger budgets for the problem if we were dealing for example, with "mammalian digestive reject bio-mass".

Although this paper is entitled "Historical Background to Sludge Disposal" I hope in the next twenty minutes or so not only to discuss its history but to place the subject in its context within the general framework of waste management. I should also like to explain the background to this seminar and to do so I shall first explain very briefly certain changes within the Ministry of Environment.

Some of you may know that this Ministry now includes an Environmental Management Division under which is a Waste Management Branch. The latter used to be called the Pollution Control Branch abbreviated to P.C.B. and we can all be glad to be no longer confused with the Pollution Control Board or with polychlorinated biphenyls. The unit below the branch level is now called a section rather than a division and in Waste Management there are to be either two or three of them, one of which is named "Pollution Control" and one "Resource Recovery". The regulatory role that used to be carried out by the Pollution Control Branch will now be carried out by the Pollution Control Section and the Regional Offices of a newly constituted Regional Operations Division.

The role of the new Resource Recovery Section is to promote, as may prove feasible, the reuse of materials now discarded. This task involves examining all the waste streams in the province and impinges on most manufacturing processes as well as the existing organizations which handle and dispose of such wastes. Our task has been described as promoting a conserver society and whilst it has been impossible to devote much time to publicity so far, this will be an essential element

in achieving our goals. One task in this regard is to inform ourselves and others of technology and of changes in technology, and it is therefore planned to sponsor a number of seminars similar to this one, in cooperation with other groups, as may be appropriate.

"Multi-disciplinary" became a catch-word, some years ago, to describe the approach that was going to be needed in the future to protect our environment. However, whilst there have been changes, it is still true to say that for the most part municipal engineers get together with other municipal engineers, foresters with foresters and so on. I hope in the seminars that we sponsor, to somewhat change that image, because it is indeed important that a multi-disciplinary approach be made to Resource Recovery. We have here today people whose interest is in agriculture, forestry, municipal waste disposal and other subjects and I hope the approach we have taken is able to satisfy you all. We would welcome any comments as to how to improve future seminars or suggestions for subjects which should be encompassed and we would welcome your ideas about recovering resources now wasted.

In compiling my comments about history I am indebted to various texts and in particular would mention "The History of Sewage Treatment" compiled by H.H. Stanbridge on behalf of the Institute of Water Pollution Control. Before commencing this historical review I would mention that, whilst the meaning of sludge needs little explanation, the quality, characteristics and concentration of suspended solids in sewage entering treatment plants varies with the standard of living of the communities served, the extent of industry connected to the systems, the per capita usage of water and the type and adequacy of the sewer systems.

The first reference we find in modern times to sludge problems is of a practice introduced in Edinburgh, Scotland of excavating pits to intercept sewage, the contents of which were thrown onto the banks to dry and then carted to land. I shall not elaborate on the horror story of sewage disposal as the nineteenth century developed but those of you who wish to study this matter may read of it in the introductory sections

of Fair and Geyer's book "Water Supply and Waste-water Disposal". I believe such reading is most valuable in putting current problems in their proper perspective. I shall simply mention a few highlights of our progress in improving our lot.

In 1800, L.H. Moures of Vesoul in France discovered that under anaerobic conditions, part of the organic content of sludge liquefied.

In 1885, Didbin in London started settling sludge in a separate tank. He recorded his experiment as follows:

> "I upended an old 30 foot boiler and used this as a tank 20 or 30 feet deep and filled it with sludge and allowed it to rest. Windows were placed at intervals to watch the process. After a week, a lively fermentation was taking place, the sludge overflowing down the sides and clear water appearing at the bottom. The staff was in a state of incipient rebellion on account of the stink" --this experiment became known as the "pot of porter".

Didbin corresponded with a Rudolf Herring from the U.S.A. and in 1899 experimental facilities were designed at Massachusetts which periodically removed the solids from settlement tanks into separate covered tanks, originally providing 15 days retention but finally reduced to a few days only. By 1901, the tank was full and the experiment discontinued. However, Clark, who was in charge of this experiment was confident that sludge volumes could be greatly reduced by such a technique.

In Birmingham in 1908, large earth lagoons were filled with sludge from septic tanks and after a time it was found the offensive odour had disappeared. After 18 months, when the supernatent was run off, an inoffensive slurry remained which dried on land to a hard odourless cake.

In 1912, two stage digestion was adopted. Further experiments followed and for many years Birmingham operated a system of seeding raw sludge from sedimentation tanks with digested sludge from the secondary tanks.

Apart from the Massachusetts experiment, you will note that up to this time everyone depended on use of open tanks at atmospheric temperature. However, during the 1920's experiments began in heating the sludge using enclosed tanks and collecting the gas. A patent to collect gas for reuse was taken out in 1930 and heated digestion tanks with gas collectors become common practice by the time of the second world war. During this period, it was recognized that whilst long periods were required for liquor separation, gasification occurred early in the process. It was therefore economic to provide primary tanks for the initial period as it was costly to heat the sludge and collect the gas. Open tanks of simple construction could be used to complete the process. It was found the main requirements for primary tanks were to seed with digesting sludge, mix well, control scum, remove grit from the floor, heat the sludge and collect the gas.

Gas use for heat also commended in the 1920's and for power in the 1930's. For major installations, electrical generation to allow power to be fed into a district grid system commenced. It used to be said the economical cut-off for such systems was a facility serving a population of about 1,000,000 but with recent changes in the energy picture I am uncertain of the current position. Incidentally, vehicles ran on compressed sludge gas in the last war and experiments to extend this practice were being carried out in 1973.

The pros and cons of mesophilic digestion versus thermophilic digestion were the subject of experiments in Leeds in 1927 and in Manchester from 1931 to 1935. Mesophilic digestion takes place at temperatures of about 28^{o}C and thermophilic at 48^{o}C. The latter was found more costly, less stable and gave rise to stronger liquors, so mesophilic digestion has generally been adopted since then.

As one draws nearer to the present age, observations become less and less a matter of history and it becomes difficult to separate the significant from the passing phase. I shall be content to mention a few general trends.

Firstly, the growing number of chemicals of every kind which started to be produced in the 1950's and 1960's led on a number of occasions to toxicants reaching sludge digestion tanks which were sufficiently potent to kill the bacteria. The result was enough to agrieve the most reasonable works manager and displease anyone downwind of the plant for some distance. For this reason, sludge digestion became less acceptable and a number of alternatives were introduced. Incineration, in particular, became more popular.

Secondly, aerobic digestion, being the aeration of sludge in open tanks, came into vogue, especially in smaller plants. The resultant sludge is not stable and is harder to handle. However, this system may represent an economic saving on small systems as compressed air is in any case necessary for most treatment plants.

Thirdly, concerns began to be expressed about the quality of sludge which heretofore had been applied to land without too much concern. As chemical addition to remove nutrients became popular, particularly near the Great Lakes, disposal of sludges became more difficult and it was recognized that, sludge quality degradation and effluent quality improvement go hand in hand.

As always, the nearer we draw to our own day the more controversy there is as to what is best.

As industrial connections to sewer systems come under control, individual dischargers must provide facilities to ensure that quality criteria are met. Wastes much stronger than domestic sewage may have to be reduced to more acceptable levels, and substances that could damage sewers or which are not biodegradable must be removed. This

will include such toxicants as heavy metals from plating plants and will almost invariably entail settlement tanks and the production of sludges or slurries at the industrial site. Accordingly, in an industrial area, as the quality of sewage entering a sewage treatment plant becomes more amendable to production of useable sludges by regulation of connections, other sludges will arise for which disposal is a problem. Sometimes an industrial sludge may be concentrated to recover useable material but generally this is not economically feasible. Indeed, it is not evident that it is always best to produce sludges with high levels of toxicants for disposal. The alternative is to allow them to be widely diffused in the environment by massive dilution with the great volume of water used as a carrier in the sewer system and subsequently by the further dilution afforded by the receiving waterway to which the effluent discharges. A case by case judgement has to be made and the amount of evidence is usually such that it is a rather arbitrary one. It can, however, be agreed that where communities have a substantial amount of industry, control of sewer connections is normally thought necessary and therefore there will be many sludges for disposal.

May I suggest it is also valuable to consider this matter in another way. To date, treatment plants which are intended to receive nondomestic waste, for whatever reason, are commonly designed, or at least some think they should be designed, to reduce the toxicants in the liquid fraction. This is in order to improve effluent quality for discharge to receiving waters. The techniques employed will degrade the sludge for discharge to land. The receiving waters run to the sea, but the land doesn't run anywhere. Accordingly, the desirability of such effluent improvement may commonly be established but is not automatic. It may also be noted that as controls on disposal of sludge to land are introduced, there may be significant impacts on policy regarding connection of industrial wastes to sewer systems and these in turn may modify the type of treatment works which are necessary.

I do not propose in this address to consider the history of dewatering techniques for sludges, other than to say that there are various well-established systems, whether by drying beds or mechanical means, which can be used to lower the water content in sludge, either raw or digested, so that it may be more readily handled and to provide an opportunity to treat the resultant liquors. Sludge that has not been dewatered, even if given secondary digestion, may still be disposed of by sparging from the back of a septic tank carrier or by pumping to be discharged through spray-guns or distributed by earth channels and berms.

Having thus explained that treatment plants which do not incinerate their sludge produce sludges which may be raw, aerobically or anaerobically digested and may be dewatered or otherwise, the question is what happens to it. The answer is that it is put on land, or it is burnt or it is put into the sea. Where volumes are too small, the latter is not an economic proposition but the reverse is true for larger cities on the seacost. Many of you may know that sea-discharge recently became very unpopular in the United States and I shall refer to that situation at the end of my paper.

The burning of sludge for energy recovery is an arguable proposition which is, I think, outside the bounds of this seminar.

As for disposal to land, there is little "history" to recount. Suffice it so say that for the most part sludge has been deposited on land since time immemorial, including over some 150 years of industrial development. All the unwanted by-products of the metal industry and others using toxic materials are still around somewhere. It is important that in identifying a problem today, we consider whether it is old, and the identification new, or whether we really have a new problem.

The same applies to the benefits. To the extent that sludge has been applied to agricultural land, its resource value has always been recovered. The new task is to optimize this recovery without environmental hazard.

However, I would mention four relatively new variants in the age-old practice of putting sludge on land:

Firstly, equipment has been developed in recent years, of which many of you will know, that allows injection of sludge some 18" below the surface. This is an alternative now available to the more conventional techniques I have already mentioned. From an agricultural viewpoint this is a considerable benefit, and from an aesthetic viewpoint, it overcomes odour problems. The question that to my knowledge remains unanswered is whether it overcomes the need to digest sludges and to install the costly equipment necessary to achieve such digestion. It seems possible to me that it does, particularly for smaller installations. Perhaps the land would have to be left fallow for some period to ensure that pathogens did not survive. If so, it should be possible to establish an economic relationship between the cost of land left fallow and the cost of digestion. Alternatively, perhaps such land could be seeded for grazing in alternate years.

Secondly, recent experiments hold promise that sludge applied to forest land may enhance tree growth. We are particularly pleased to have Mr. Domenowske with us from Metropolitan Seattle who will be speaking on this topic this afternoon.

Thirdly, sludge may be used to reclaim old refuse sites or other waste land such as by developing parks or other recreational areas.

Fourthly, before applying to land, sludge may be composted with other wastes.

We recognize the need to protect land in the province over the generations ahead for whatever use is deemed best. We also recognize, as above, that any criteria adopted for sludge disposal facilities but on treatment plants and control of connections to sewers. Accordingly, the Resource Recovery Section has distributed to interested bodies throughout the province, information about this matter so that we may receive input in formulating policy. Mr. Wetter will be speaking on this topic this afternoon. We hope today's seminar will help us in this endeavour and that those with views on this subject will express them in the panel discussion.

I would add that we have a particular problem in considering the composting of sludges with hog fuel. There are three projects proceeding to our knowledge at this time, one of which is to be the subject of Mr. Steven's paper this afternoon. They appear promising and have proceeded in the absence of specific provincial requirements. Furthermore, the capital involved is not very substantial so that if provincial requirements are introduced necessitating some change, little will have been wasted. However, what is significant in terms of capital expenditure is the saving that might be made in sludge treatment facilities, if indeed the Kelowna operation is proved satisfactory. Possibly certain criteria may have to be met before such savings can be realized and logistics may well dictate the need for digestion over some volume limit. We need to define such criteria. This, we view as a matter of some urgency and we have therefore set up an inter-agency committee between the Ministry of Health, the Ministry of Agriculture and the Ministry of Environment to monitor the three operations to which I have referred. Preliminary information reveals that we must not be sanguine about this matter and controls that will dictate changes are a possibility.

Once again this is a matter which I hope will be aired during the discussion period.

I close this presentation by drawing your attention to just one of many decisions in this field. I quote from a paper by Gabriel Gillie' of the National Institute for Water Research, South Africa, presented at an international conference in Melbourne, Australia in October of last year where he discussed disposal of sludge to the sea from Los Angeles:

> "Available scientific evidence showed that the practice was environmentally sound and satisfactory, was not causing irreversible change and may, in fact, have been beneficial. Legal requirements, however, demanded that marine discharge be discontinued which necessitated an additional capital cost of approximately $10,000,000 and an increase in operating and maintenance costs of about $6,000,000 per annum while a substantial negative environmental impact resulted from the consumption of additional energy, equivalent to some 60,000 barrels of oil per year."

We don't all have to agree with Mr. Gillies' viewpoint but we can all agree that we must not spend taxpayers money before we are sufficiently well informed to produce sound policies.

SLUDGE QUANTITIES FROM WASTE TREATMENT PROCESSES

BY

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SLUDGE QUANTITIES FROM WASTE TREATMENT PROCESSES

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1. INTRODUCTION

The design of sludge handling and disposal facilities has been one of the most neglected aspects of wastewater treatment facility design. This is not without reason. The most frequent excuse given is that we have no idea how much sludge will be produced and what the sludge characteristics may be. As well, in many instances we have also been vague as to the final sludge disposal or utilization option which should be persued. In general, the concern regarding sludge quantities, handling and disposal is proportional to population density, and the degree and complexity of industrialization.

This paper will focus on providing information which can be used to estimate sludge production at primary and secondary biological wastewater treatment systems.

In most of the examples provided, phosphorus removal to 1.0 $mg \cdot L^{-1}$ effluent total phosphorus using chemical addition is included.

2. SLUDGE QUANTITIES PRIOR TO ANAEROBIC DIGESTION

Waste treatment process design engineers are continually plagued by lack of information when it comes to designing sludge handling and disposal/utilization facilities. Sludge production is influenced by a number of variables.

For conventional primary plants influent solids, overflow rate, temperature and general waste characteristics influence the quantity of sludge which requires handling and disposal.

When chemicals are added to primary plants additional factors such as type of chemical, chemical dosage and point of chemical addition influence sludge quantities produced.

For biological sludge production, the type of process used in the conversion of substrate (hence SRT) greatly affects the amount of biomass

produced. The amount of sludge produced also varies with the nature of substrate oxidized and nutrient availability. Higher sludge volumes result in winter than in summer because the auto-oxidation rate depends on temperature.

The total volume of sludge produced from biological and physical/chemical systems, or any combination thereof is also influenced by clarifier performance, sludge recycle and the degree of operator attention to the system.

A most useful method of sludge quantity estimation consists of performing a mass balance around various treatment process components and coupling this with process efficiency assumptions (1). Calculations to determine chemical sludge quantities based on stoichiometric relationships is another popular approach (2). Bench scale and pilot scale studies would appear to provide more specific information which can be used in the design of full scale sludge handling and disposal/utilization facilities.

Examples of data from bench scale, pilot scale and full scale treatment systems will illustrate some of the difficulties associated with sludge quantity determinations.

2.1 Primary Plants

Figure 1 summarizes the data from 15 conventional, primary plants (without precipitant addition) surveyed covering a range of hydraulic loadings from 0.26 to 11 MGD*. The data show that 50% of time 1 995 gallons of sludge are produced for each million gallons of wastewater treated. This translates to 1 140 lbs dry solids for each million gallons treated (Figure 2). The total solids concentrations of the raw primary sludges varied from 3.5 to 8% with a mean of 5.7%.

2.1.1 Upgraded primary plants

Upgraded plants are defined as those plants where chemicals are added for phosphorus removal to achieve an effluent total phosphorus concentration of 1.0 $mg \cdot L^{-1}$.

2.1.2 Stoichiometric calculation

In the case of physical-chemical processes, it would appear that calculations based on stoichiometry would result in pretty close sludge quantity estimates. This is not always so, but certainly gives an excellent

*Imperial gallons used throughout this paper

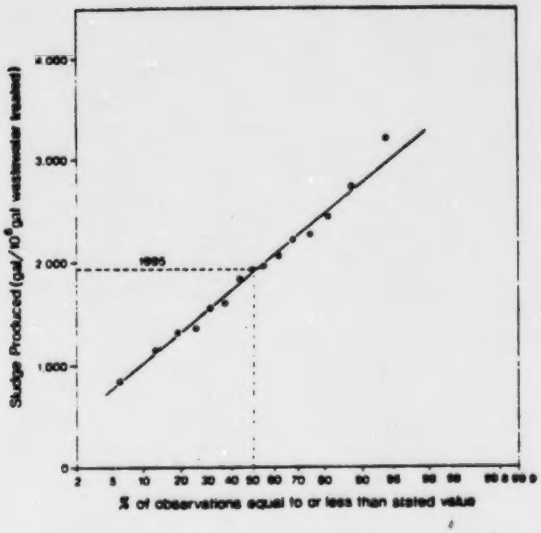

FIGURE 1. PROBABILITY DISTRIBUTION FOR SLUDGE VOLUME PRODUCED AT CONVENTIONAL PRIMARY PLANTS (3)

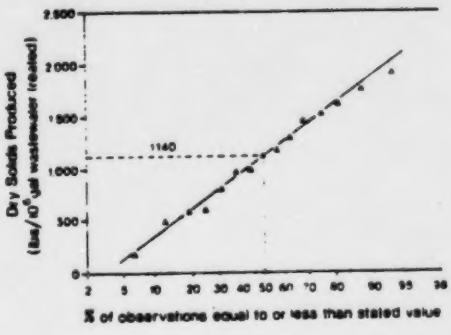

FIGURE 2. SLUDGE MASS PRODUCED AT CONVENTIONAL PRIMARY PLANTS (3)

first approximation of what to expect. Table 1 is an example of such calculations. In this particular case the objective was to reduce total phosphorus to an effluent concentration of 1.0 $mg \cdot L^{-1}$ (filtered) by using either lime, alum or ferric chloride. The calculations show that when using lime, the solids production would be 4 to 6 times greater than when using either ferric chloride or alum, respectively.

Clearly, when physical-chemical processes are either added to or superimposed on biological processes, the biological sludge quantity must be added to the chemical sludge produced.

2.1.3 Full scale - Camp Borden

The previous specific example (Table 1) was taken from a full scale phosphorus removal study conducted at the primary wastewater treatment plant at C.F.B. Borden (4). The study lasted ten months and covered three phases of chemical addition for phosphorus removal using lime, alum and ferric chloride. While the major objective of this study was to determine the optimum phosphorus removal precipitant and its dosage to achieve an effluent P objective of ≤ 1 $mg \cdot L^{-1}$, information on sludge production under various operational conditions was also collected. These data as summarized in Table 2 were compared to calculated sludge production values and are shown as a frequency distribution in Figure 3. In this case, the amount of sludge produced was overestimated by 28%, 50% of the time.

TABLE 1. EXAMPLE SOLIDS PRODUCTION CALCULATIONS (4)

		LIME ADDITION Period: 2	ALUM ADDITION Period: 6	FERRIC CHLORIDE ADDITION Period: 10
CHEMICAL REACTIONS		1. softening $Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 \downarrow + 2H_2O$ (100 as $CaCO_3$)(74) (200) 2. phosphorus precipitation $10\ Ca(OH)_2 + 6\ PO_4^{3-} \rightarrow Ca_{10}(PO_4)_6(OH)_2 \downarrow + 8(OH)^-$ (740) (186 as P) (1004) 3. hydroxide consumption $Ca(OH)_2 + CO_2 \rightarrow CaCO_3 \downarrow + H_2O$ (74) (44) (100)	$Al^{3+} + PO_4^{3-} \rightarrow AlPO_4 \downarrow$ (27) (31 as P) (122) $Al^{3+} + 3\ OH^- \rightarrow Al(OH)_3 \downarrow$ (27) (51) (78)	$Fe^{3+} + PO_4^{3-} \rightarrow FePO_4 \downarrow$ (56) (31 as P) (151) $Fe^{3+} + 3OH^- \rightarrow Fe(OH)_3 \downarrow$ (56) (51) (107)
ASSUMPTIONS		since total hardness > total alkalinity carbonate hardness = alkalinity assume wastewater has 10 mg/l CO_2	0.87 mg Al^{3+} react with 1 mg P to form 3.2 mg $AlPO_4$ 1.0 mg Al^{3+} reacts with 1.9 mg OH^- to form 2.9 mg $Al(OH)_3$	1.8 mg Fe^{3+} reacts with 1 mg P to form 5.8 mg $FePO_4$ 1.0 mg Fe^{3+} reacts with 0.91 mg OH^- to form 1.5 mg $Fe(OH)_3$
PLANT DATA		Period 2 dosage = 151 mg/l $Ca(OH)_2$ flow = 4545 m^3/d	Period 6: dosage = 4.4 mg/l as Al^{3+} flow = 3864 m^3/d	Period 10 dosage = 9.6 mg/l as Fe^{3+} flow = 3818 m^3/d
	EFFLUENT/INFLUENT	SS = 51 mg/l TFP = 2.0 mg/l P Alkalinity = 251 mg/l $CaCO_3$	SS = 67 mg/l TFP = 3.2 mg/l P	SS = 89 mg/l TFP = 3.8 mg/l P
		SS = 14 mg/l TFP = 0.9 mg/l P Alkalinity = 204 mg/l $CaCO_3$	SS = 31 mg/l TFP = 1.0 mg/l P	SS = 33 mg/l TFP = 0.9 mg/l P
		TFP removed = 1.1 mg/l P	TFP removed = 2.2 mg/l P	TFP removed = 2.9 mg/l P
CHEMICAL SOLIDS PRODUCTION	SOLIDS	Due to Softening Reaction (251-204) mg/l $CaCO_3$ remove $\frac{100\ mg CaCO_3}{100\ mg CaCO_3\ hardness}$ = 94 mg/l $CaCO_3$		
		$Ca(OH)_2$ Consumed in Softening Reaction: (251-204) mg/l $CaCO_3$ $\frac{74\ mg\ Ca(OH)_2}{100\ mg\ CaCO_3}$ = 34.8 mg/l $Ca(OH)_2$		
	SOLIDS	Due to $Ca_{10}(PO_4)_6(OH)_2$ Formation: 1.1 mg/l P removed x $\frac{1004\ mg\ Ca_{10}(PO_4)_6(OH)_2}{186\ mg\ P}$ = 5.9 mg/l $Ca_{10}(PO_4)_6(OH)_2$	Due to $AlPO_4$ Formation: 2.2 mg/l P removed x $\frac{3.9\ mg\ AlPO_4}{1\ mg\ P}$ = 8.6 mg/l $AlPO_4$	Due to $FePO_4$ Formation 2.9 mg/l P removed x $\frac{5\ mg\ FePO_4}{1\ mg\ P}$ = 14.2 mg/l $FePO_4$
		$Ca(OH)_2$ Consumed in Phosphorus Removal 1.1 mg/l P removed x $\frac{740\ mg\ Ca(OH)_2}{186\ mg\ P}$ = 4.4 mg/l $Ca(OH)_2$	Al^{3+} Consumed in $AlPO_4$ Formation 2.2 mg/l P x $\frac{0.87\ mg\ Al^{3+}}{1\ mg\ P}$ = 1.9 mg/l Al^{3+}	Fe^{3+} Consumed in $FePO_4$ Formation 2.9 mg/l P x $\frac{1.8\ mg\ Fe^{3+}}{1\ mg\ P}$ = 5.2 mg/l Fe^{3+}
	SOLIDS	OH^- Consumption due to CO_2: 10 mg/l CO_2 x $\frac{100\ mg\ CaCO_3}{44\ mg\ CO_2}$ = 22.7 mg/l $CaCO_3$	Due to $Al(OH)_3$ Formation: (4.4-1.9) mg/l Al^{3+} x $\frac{2.9\ mg\ Al(OH)_3}{1\ mg\ Al^{3+}}$ = 7.3 mg/l $Al(OH)_3$	Due to $Fe(OH)_3$ Formation: (9.6-5.2) mg/l Fe^{3+} x $\frac{3.9\ mg\ Fe(OH)_3}{1\ mg\ Fe^{3+}}$ = 8.4 mg/l $Fe(OH)_3$
		$Ca(OH)_2$ Consumed in CO_2 Reaction: 10 mg/l CO_2 x $\frac{74\ mg\ Ca(OH)_2}{44\ mg\ CO_2}$ = 16.8 mg/l $Ca(OH)_2$		
		$Ca(OH)_2$ Excess: $Ca(OH)_2$ dose - $Ca(OH)_2$ consumed = 151 mg/l - (34.8 + 4.4 + 16.8) mg/l = 95 mg/l $Ca(OH)_2$		
	SOLIDS	Inerts in $Ca(OH)_2$ [96% $Ca(OH)_2$] = 151 mg/l $Ca(OH)_2$ x 0.04 = 6 mg/l Inerts		
	CHEMICAL SOLIDS TOTAL	Due to Softening : 94 mg/l Due to $Ca_{10}(PO_4)_6(OH)_2$ Formation: 5.9 mg/l Due to CO_2 : 22.7 mg/l Due to $Ca(OH)_2$ Excess : 95 mg/l Due to Inerts : 6 mg/l Σ = 224 mg/l	Due to $AlPO_4$ Formation: 8.6 mg/l Due to $Al(OH)_3$ Formation: 7.3 mg/l Σ = 15.9 mg/l	Due to $FePO_4$ Formation 14.2 mg/l Due to $Fe(OH)_3$ Formation 8.4 mg/l Σ = 22.6 mg/l
SOLIDS BALANCE	IN	Due to Chemical Addition : 224 mg/l Influent SS : 51 mg/l Σ = 275 mg/l	Due to Chemical Addition 15.9 mg/l Influent SS : 67 mg/l Σ = 83 mg/l	Due to Chemical Addition 22.6 mg/l Influent SS : 86 mg/l Σ = 109 mg/l
	OUT	Effluent SS : 14 mg/l	Effluent SS : 31 mg/l	Effluent SS : 33 mg/l
	REMOVED	Total Solids In : 275 mg/l Total Solids Out : 14 mg/l ΔΣ = 261 mg/l	Total Solids In : 83 mg/l Total Solids Out : 31 mg/l ΔΣ = 52 mg/l	Total Solids In : 109 mg/l Total Solids Out : 33 mg/l ΔΣ = 76 mg/l
TOTAL SOLIDS PRODUCTION		261 mg/l x 4545 m^3/d x 1000 l/m^3 x 10^{-6} kg/mg Σ = 1186 kg/d	52 mg/l x 3864 m^3/d x 1000 l/m^3 x 10^{-6} kg/mg Σ = 201 kg/d	76 mg/l x 3818 m^3/d x 1000 l/m^3 x 10^{-6} kg/mg Σ = 290 kg/d

TABLE 2. CAMP BORDEN SLUDGE PRODUCTION - PRIMARY PLANT (4)

P-Removal Precipitant		Sludge Mass Produced				Ratio of Measured to Calculated Value
Chemical	Dosage	Calculated		Measured		
-	mg/l	kg/d	lbs/10^6gal	kg/d	lbs/10^6gal	
Baseline	-	116	255	191	420	1.65
Lime	151[1]	1186	2609	1148	2526	0.97
	197	1389	3056	1400	3080	1.01
	275	3184	6426	1697	3425	0.53
	210	1876	3857	1399	2876	0.76
Alum	4.4[2]	201	520	332	859	1.65
	7.5	385	1020	283	750	0.74
	14.8	645	1730	253	679	0.39
	18.5	604	1601	294	779	0.49
Ferric Chloride	9.6[3]	290	760	304	796	1.05
	14.6	321	872	307	834	0.96
	19.0	502	1331	312	827	0.62
	26.6	515	1382	343	920	0.67

[1] as $Ca(OH)_2$
[2] as Al^{3+}
[3] as Fe^{3+}

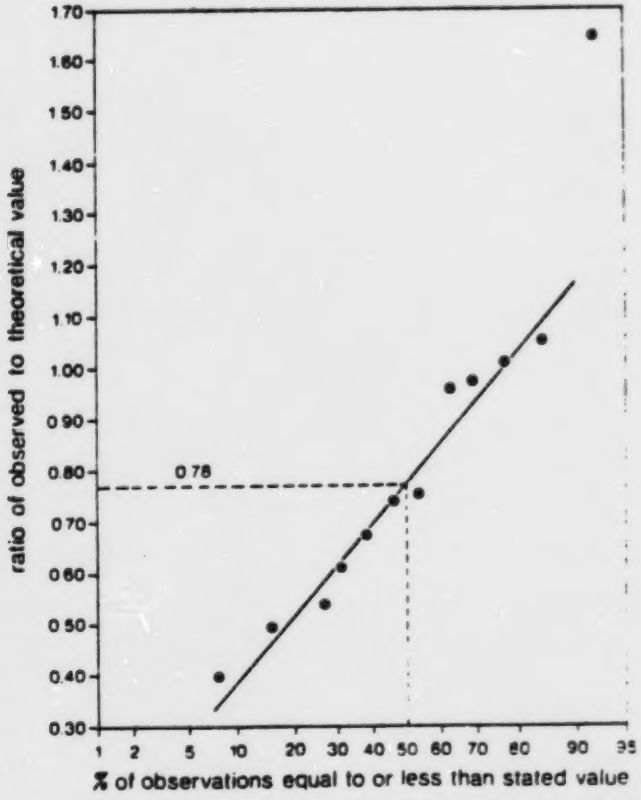

FIGURE 3. OBSERVED TO THEORETICAL SOLIDS PRODUCTION RATIO-PRECIPITANT ADDITION TO A FULL SCALE PRIMARY PLANT (4)

2.1.4 Full scale - Ontario survey data

As effluent objectives become more stringent, treatment process complexity increases and sludge quantities increase as well.

For example, the impact of chemical addition for phosphorus removal at primary plants is illustrated in Figure 4 for seven upgraded plants. In these plants, the average sludge solids concentration decreased from 6.0 to 5.3% after chemical addition. The sludge mass increased by 40%.

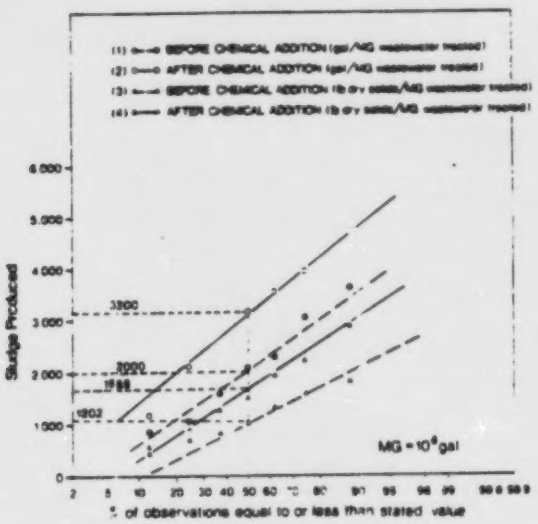
(1) BEFORE CHEMICAL ADDITION (gal/MG wastewater treated)
(2) AFTER CHEMICAL ADDITION (gal/MG wastewater treated)
(3) BEFORE CHEMICAL ADDITION (lb dry solids/MG wastewater treated)
(4) AFTER CHEMICAL ADDITION (lb dry solids/MG wastewater treated)
Sludge Produced
6 000
5 000
4 000
3 000
2 000
1 000
0
3800
3000
1900
1202
MG = 10⁶ gal
2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9
% of observations equal to or less than stated value

FIGURE 4. PROBABILITY DISTRIBUTION FOR SLUDGE PRODUCED AT PRIMARY PLANTS WITH ADDITION OF METAL SALTS (3)

2.1.5 Use of Lime

Because few Ontario plants practice P removal using lime, no substantive data base for sludge quantity estimation exist. However, based on past experience at a number of pilot and full scale facilities practicing P removal using lime, reasonable estimates of sludge production can be made.

The mass of sludge produced will depend largely on the wastewater alkalinity and the lime dosage required to attain a specific pH at which the target P effluent level is achieved.

Figure 5 illustrates that, having determined the pH at which the P effluent target will be achieved, the correlation will predict the required

lime/alkalinity ratio. Knowledge of the wastewater alkalinity enables calculation of the required lime dosage (5). Another correlation (6) for raw wastewaters from 20 Ontario municipalities indicating lime dosage requirements to attain pH 10 and 11 for various alkalinity values is shown in Figure 6.

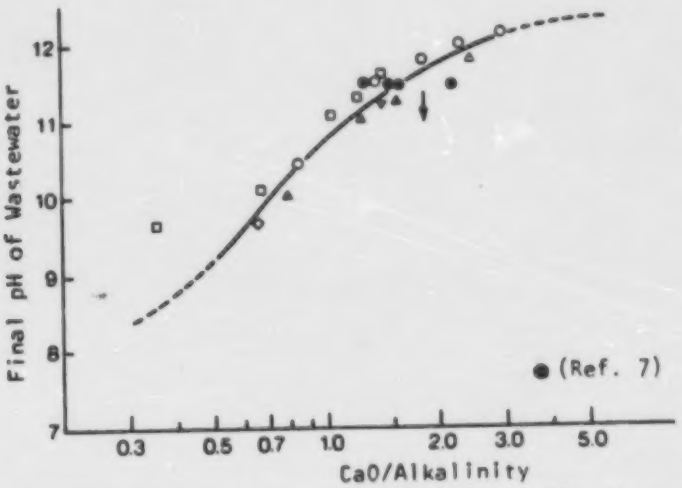

FIGURE 5. RATIO OF LIME DOSAGE ($mg \cdot L^{-1}$) TO INITIAL WASTEWATER ALKALINITY (5)

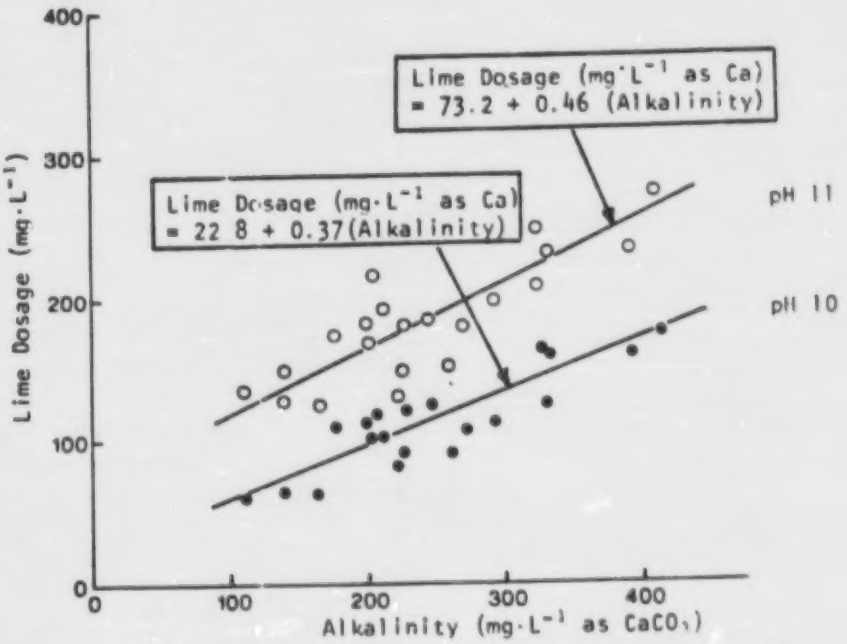

FIGURE 6. LIME DOSAGE VS. WASTEWATER ALKALINITY (6)

Brouzes (7) in his bench scale experiments examining the use of lime in the treatment of municipal wastewaters also monitored sludge production. Figure 7 illustrates sludge production as a function of pH for the municipal sewage from Beaconsfield, Quebec.

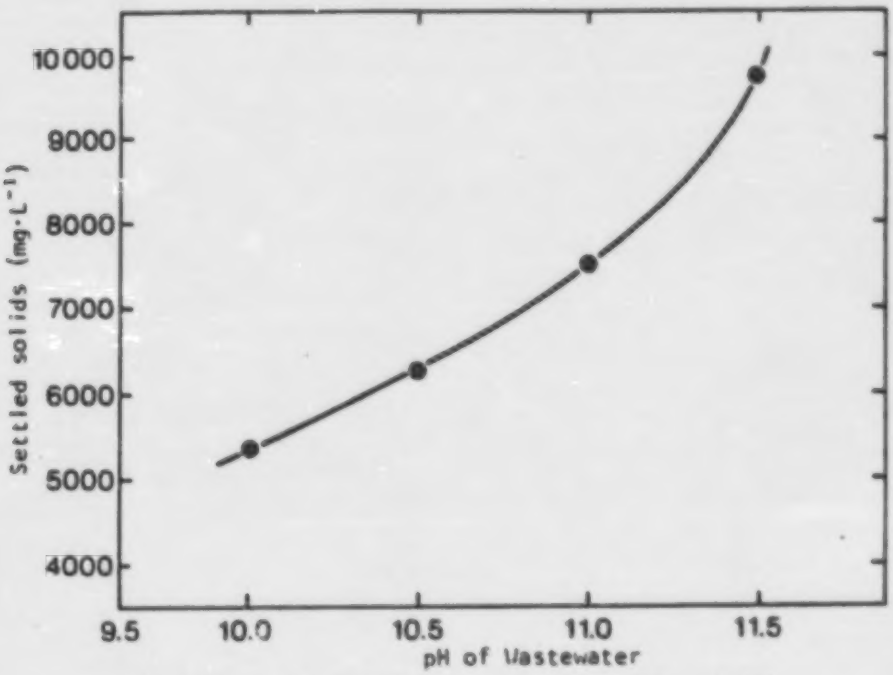

FIGURE 7. SLUDGE VOLUME AS A FUNCTION OF pH (7)

At a tertiary treatment facility for P removal at Ely, Minnesota, the sludge volume due to lime addition for P removal to extremely low levels (0.05 $mg \cdot L^{-1}$ at pH 12) increased by 700% (8).

The available information in the literature quite clearly demonstrates that for lime treatment systems sludge volumes are many times greater than for any other treatment process. This may not necessarily result in a disposal problem inasmuch as lime can be recovered from the sludge and reused in the process. In this case it would be more of a materials handling problem.

2.1.6 Summary - Sludge quantities from primary plants

The information as it relates to full scale plant data previously presented is summarized in Table 3. Chemical addition for total phosphorus removal to 1.0 mg/L using metal salts resulted in a 60 percent sludge volume increase.

TABLE 3. PRIMARY SLUDGE PRODUCTION DATA (3)

Description	Units	Sludge Production		
		Prior to Chemical Addition	After Chemical Addition	Percent Change
Volume	gal*/10^6	2000	3200	+60
	gpcd**	0.29	0.46	-
	% of influent Q	0.20	0.32	-
Mass	lbs/10^6 gal	1202	1688	+40
	lbs pcd**	0.17	0.24	-
Solids	percent	6.0	5.3	-0.7
Number of Plants	-	7	7	-

* Imperial gallons used throughout this paper.

** pcd = per capital day

2.2 Secondary - Biological Plants

The literature abounds with sludge production data from biological treatment plants. Figure 8 is just one example for municipal sludges and illustrates the degree of variability, which can be in excess of 100%. In this case sludge production for various biological treatment processes is shown.

2.2.1 Principles of biological sludge production

Sludge quantities can be estimated from bench and pilot scale data when considering biological principles. Figure 9 shows that normally micro-organisms experience a growth history which consists of 3 phases. A logarithmic (a - b) a declining growth (b - c) and an auto-oxidation (c - d) phase. The net accumulation of sludge due to this synthesis and oxidation can be expressed by:

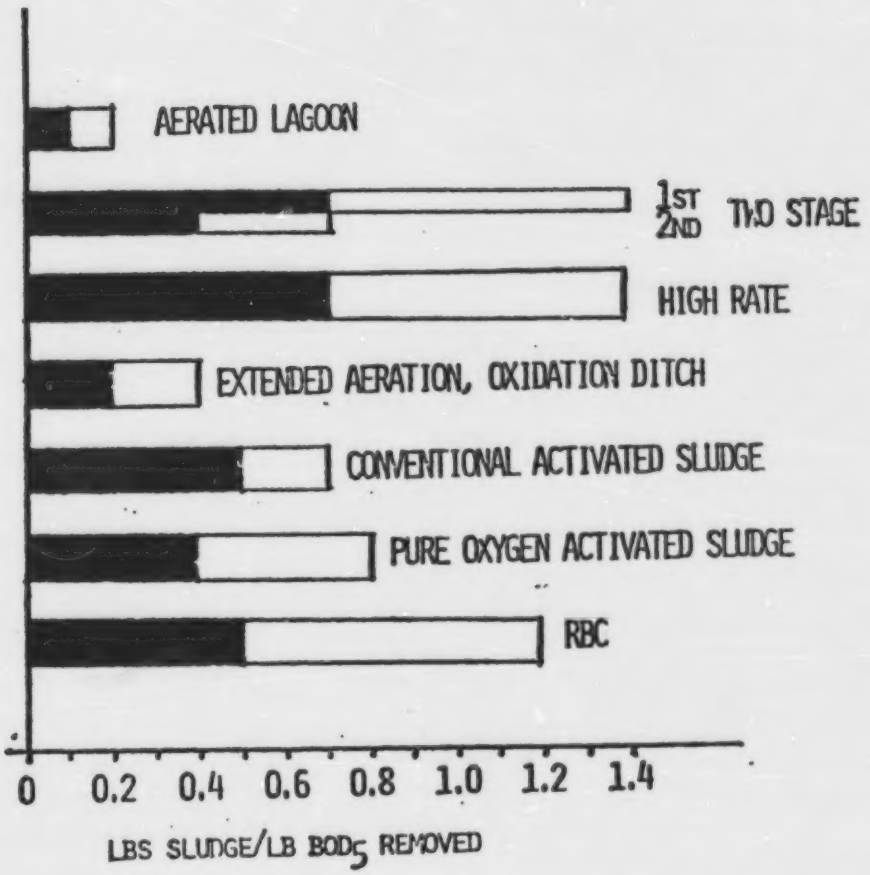

FIGURE 8. BIOLOGICAL SLUDGE PRODUCTION (9)

lbs VSS produced/day = a(lbs BOD_5 removed/day) - b(lbs MLVSS) (1)

where:

a = the fraction of BOD_5 removed and synthesized to new sludge

b = the mean rate of auto-oxidation (endogenous respiration) as a fraction per day

MLVSS = lbs of MLVSS under aeration

In addition there are usually non-oxidizable volatile solids present. These and the inert particulate solids leaving the primary sedimentation tank are assumed to be trapped in the sludge and hence, must be taken into account when calculating the total amount of sludge production.

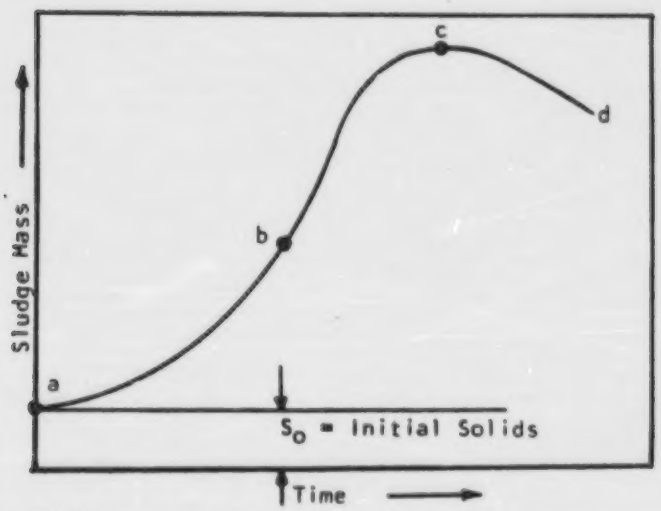

FIGURE 9. SLUDGE GROWTH

It is convenient to express equation (1) in the general format of:

$$y = mx - b$$

$$\frac{\text{lbs VSS produced/day}}{\text{lbs MLVSS}} = a \frac{\text{lbs BOD}_5 \text{ removed/day}}{\text{lbs MLVSS}} - b \qquad (2)$$

Data obtained from bench and pilot scale studies is arranged and plotted as shown in Figure 10. This then facilitates the calculation of constants a and b.

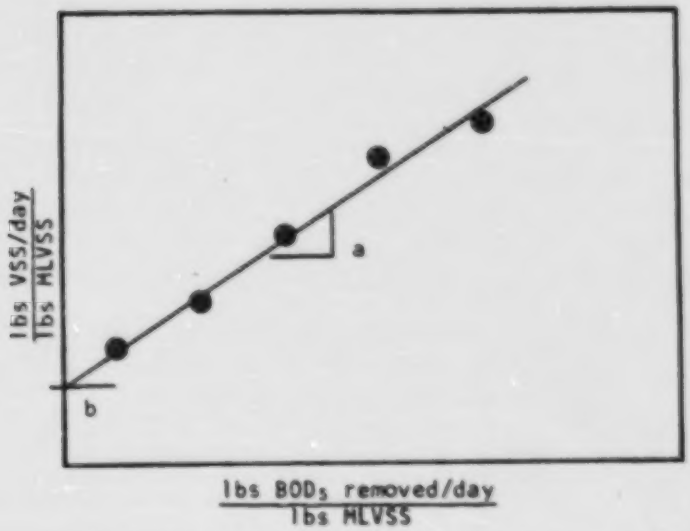

FIGURE 10. CONSTANTS FOR SYNTHESIS AND ENDOGENOUS RESPIRATION

Constants a and b are only constant for a particular wastewater under specific process conditions, and must be derived for each design situation. Past experience has shown that a may vary from 0.5 to 0.7 and b from 0.04 to 0.1 day^{-1}.

It was noted earlier that the amount of sludge produced is very much dependent on the SRT. The SRT being defined as:

$$SRT = \frac{\text{amount of volatile solids in the aeration tank}}{\text{amount of volatile solids removed daily from the system}} \quad (3)$$

$$SRT = \frac{VC_1}{Q_w C_2 + QC_3} \quad (4)$$

where:

V	= aeration tank volume	gal
Q_w	= sludge wastage rate	$gal \cdot d^{-1}$
Q	= influent flow	$gal \cdot d^{-1}$
C_1	= MLVSS	$mg \cdot L^{-1}$
C_2	= underflow VSS conc.	$mg \cdot L^{-1}$
C_3	= effluent VSS conc.	$mg \cdot L^{-1}$

Experience has shown that the activated sludge process is best controlled by attempting to maintain a constant SRT. Generally speaking the SRT may be anywhere between 3 and 12 days. Figures 11 and 12 show examples of solids production as a function of SRT for different wastes and as affected by temperature, respectively.

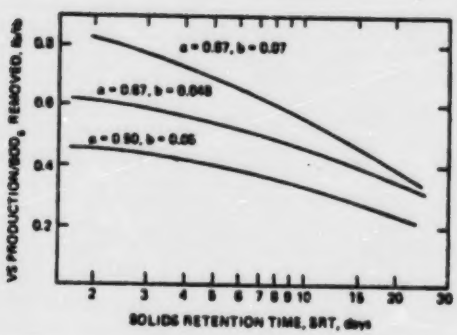

FIGURE 11. EFFECT OF DIFFERENT WASTE-WATERS (10)

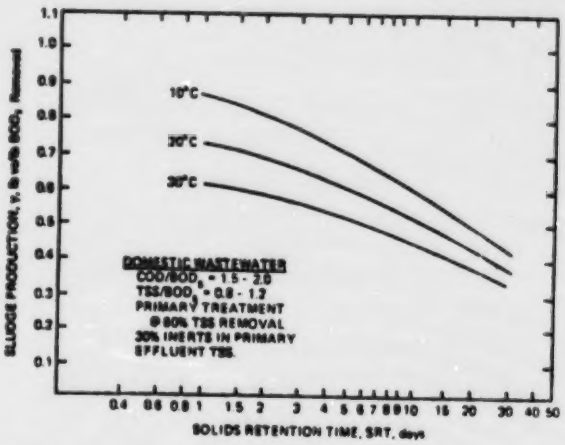

FIGURE 12. EFFECT OF TEMPERATURE (10)

2.2.2 Full scale - Ontario survey data

Sludge production data from 42 secondary plants using the conventional activated sludge process were analyzed. The plants have flow capacities ranging from 0.3 to 179 MGD. The raw sludge produced consists of both primary and waste activated sludge. In the case of conventional activated sludge plants, Figure 13 shows that 50% of the time at least 3 905 gallons of sludge are produced per million gallons treated. Solids concentrations varied from 2 to 7%, with a weighted average of 4.6%. Similarly, the dry weight of solids produced at conventional activated sludge plants was equal to or less than 1 786 lbs dry solids per million gallons of wastewater treated, 50% of the time (Figure 14).

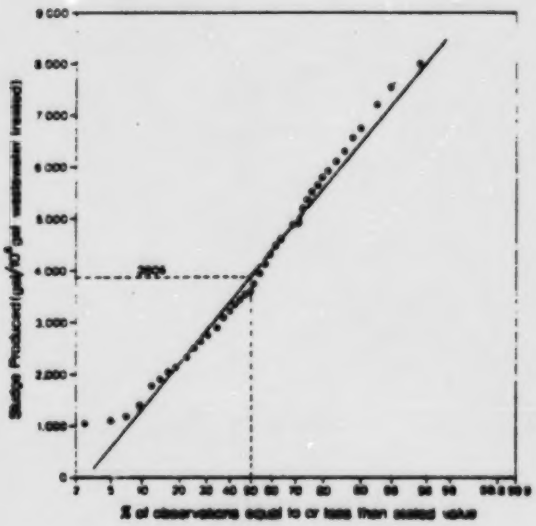

FIGURE 13. PROBABILITY DISTRIBUTION FOR SLUDGE VOLUME PRODUCED AT CONVENTIONAL SECONDARY (A.S.) PLANTS (3)

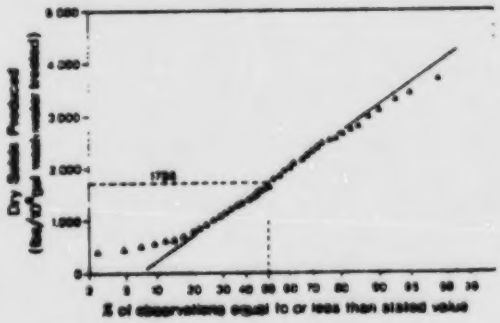

FIGURE 14. SLUDGE MASS PRODUCED AT CONVENTIONAL SECONDARY (A.S.) PLANTS (3)

2.2.3 Upgraded secondary plants

As with the primary upgraded plants, upgrading is defined as chemical addition of metal salts to attain an effluent total phosphorus objective of 1.0 $mg \cdot L^{-1}$. In the case of biological plants this involves

. . .

2.2.4 Stoichiometric vs observed results - pilot scale

A long-term pilot scale study for the removal of phosphorus and nitrogen (11) was conducted at the Wastewater Technology Centre (WTC). Sludge production was monitored over a 16-day consecutive period. Comparing the observed to calculated sludge production values for ferric iron addition based on stoichiometric relationships shows a 65% increase 50% of the time, as illustrated in Figure 15.

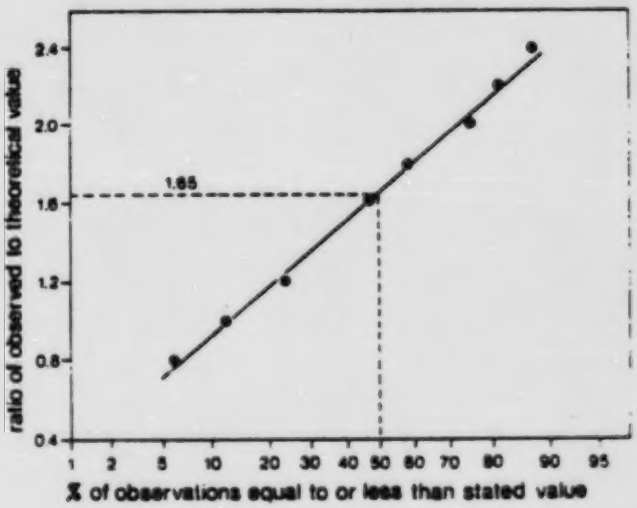

FIGURE 15. OBSERVED TO THEORETICAL SOLIDS PRODUCTION RATIO-FERRIC IRON ADDITION AT A NITROGEN AND PHOSPHORUS REMOVAL ACTIVATED SLUDGE PLANT (11)

2.2.5 Full scale - Ontario survey data

Sludge production data were obtained from a 1975 survey of Ontario wastewater treatment plants. In a number of instances, it was possible to compare sludge production prior to phosphorus removal to sludge production following installation of phosphorus precipitation systems (3).

Sludge production data for 15 secondary biological, upgraded to include phosphorus removal plants (primary, and waste activated, chemical sludge) are illustrated in Figure 16.

Fifty percent of the observations showed a solids production equal to or less than 1 725 lbs dry solids per million gallons before chemical addition. This increased to 2 170 lbs of dry solids per million gallons after chemical addition and represents a 26% increase in sludge mass. Following precipitant addition, the average total solids concentration decreased from 4.5 to 4.2%.

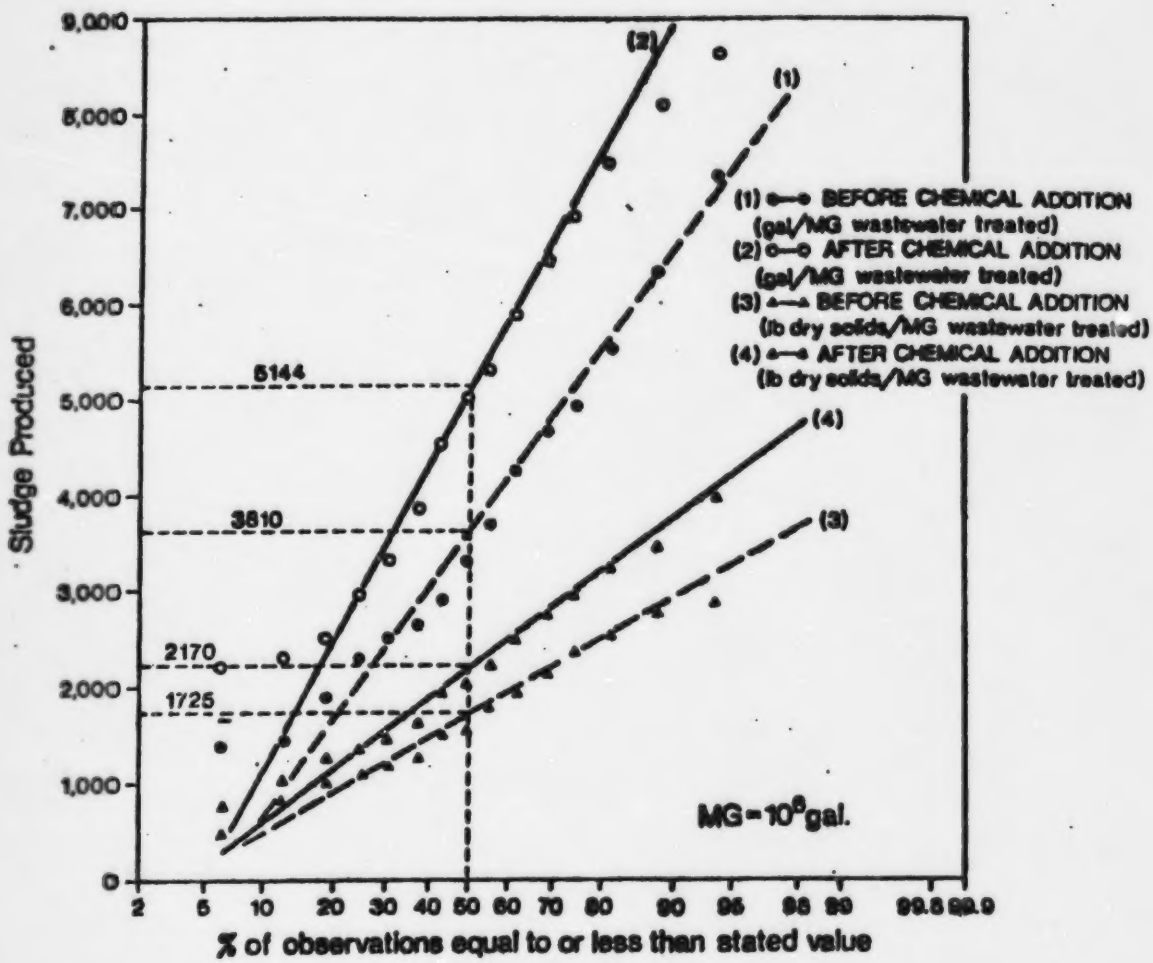

FIGURE 16. PROBABILITY DISTRIBUTION FOR SLUDGE PRODUCED AT SECONDARY (C.A.S.) PLANTS WITH ADDITION OF METAL SALTS TO AERATION TANK (3)

While metal salts are generally added to the aeration tanks, data analyzed from four installations where metal salts were added to the primary settling tank showed a decrease in solids produced. In this instance, the lower organic loading to the aeration tank due to additional organics removed in the primary, resulted in reduced biosynthesis.

It must be recognized that aside from reduced phosphorus concentrations in the effluent, there are additional benefits when chemicals are added.

In the case of metal salt addition these benefits would consist of lower SS, lower BOD_5, lower heavy metal and lower toxics levels. When lime is added similar benefits are realized. As well, additional advantages consist of a disinfected effluent, enhanced sludge dewatering characteristics and tie-up of heavy metals in the sludge flocs. On the other hand, the disposal/utilization of this sludge now concentrated with some of the undesirable constituents may pose a problem.

2.2.6 Summary - Sludge quantities from activated sludge plants

Sutton (11) underestimated sludge production by 65% when using stoichiometric relationships for a biological system with chemical addition.

From our experience, the best data base for sludge production exists in the Ontario survey of full scale treatment plants (3). The data presented in earlier figures are summarized in Table 4 for activated sludge plants.

TABLE 4. SLUDGE PRODUCTION DATA - FROM ACTIVATED SLUDGE PLANTS (3)

Description	Units	Sludge Production		
		Prior to Chemical Addition	After Chemical Addition	Percent Change
Volume	gal/10^6 gal	3810	5144	+35
	gpcd	0.55	0.75	-
	% of influent Q	0.38	0.51	-
Mass	lbs/10^6 gal	1725	2170	+26
	lbs pcd	0.25	0.32	-
Solids	percent	4.5	4.2	-0.3
Number of Plants	-	15	15	-

2.2.7 Sludge quantity predictions for lower than 1 $mg \cdot L^{-1}$ effluent P targets

The aforenoted information does not address the question of "how much more sludge would be generated when imposing point source controls for effluent total phosphorus concentrations of 0.5 $mg \cdot L^{-1}$?" Or for that matter for BOD_5 and SS concentrations of 3 to 5 $mg \cdot L^{-1}$.

A recent document (12) made a first attempt at answering this question by reporting on a computer simulation of required process modifications to meet various point source P control scenarios and the resulting sludge quantities. Figure 17 is a typical illustration of the dramatic increases in sludge mass over baseline conditions of no phosphorus removal. The example shows a simulation for 17 Canadian plants in the Lake Ontario drainage basin and represents a total flow of 582 MGD for a sewered population of 3.8 million persons. The simulation predicts a sludge mass increase from 34% over baseline conditions (no chemical addition) for an effluent total phosphorus target concentration of 1.0 $mg \cdot L^{-1}$.

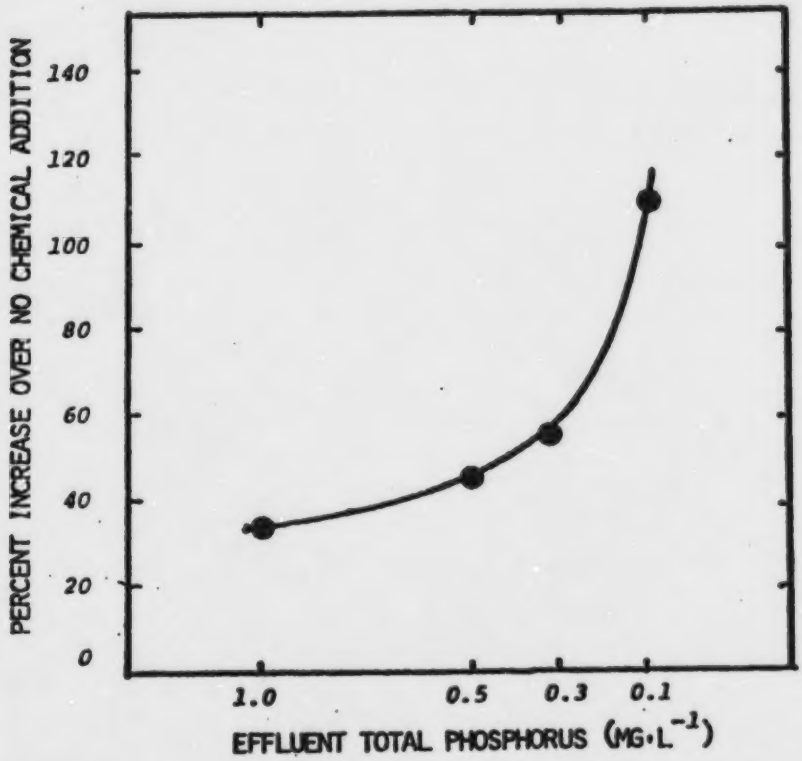

FIGURE 17. INCREASE IN SLUDGE MASS DUE TO CHEMICAL ADDITION TO MEET VARIOUS EFFLUENT TOTAL PHOSPHORUS TARGETS

This prediction compares favourable with the 1975 Ontario sludge survey data (3) indicating a 26% sludge mass increase. Treatment process modifications required to attain an effluent objective of 0.1 $mg \cdot L^{-1}$ total phosphorus predicts a 108% increase in sludge mass over baseline levels (no chemical addition).

3. SLUDGE QUANTITIES AFTER ANAEROBIC DIGESTION

The sludge production data summarized earlier, facilitates the design of sludge handling and volume reduction facilities. When designing facilities for ultimate disposal, the sludge volume after digestion must be known. Such data are difficult to obtain. In many instances, this can be attributed to incomplete records concerning volume of sludge disposed of, as well as problems associated with solids concentration determinations.

3.1 Primary Plants

The Ontario survey (3), while incomplete, provides the best, currently available data base on this subject. The data relating sludge volumes disposed from standard primary plants practising anaerobic digestion to population served were subjected to regression analysis (Figure 18).

The equation expressing this relationship for 17 plants is shown as:

$$\text{Sludge Disposal } (\times 10^{6}\ \text{gal} \cdot \text{yr}^{-1}) = 0.0169\ (\text{Population} \times 10^{-3})^{1.131} \quad (5)$$

Figure 18 illustrates the fact that digester problems will result in substantial increases in sludge volumes requiring disposal.

The data base for upgraded primary plants and the resulting sludge quantities after anaerobic digestion was inadequate for analysis.

3.2 Secondary - Biological Plants

Figures 19 and 20 illustrate from the available Ontario data (3) relationships between volume or mass of sludge to be disposed of from conventional activated sludge plants as a function of population served.

Similarily, Figures 21 and 22 show sludge volume and mass as functions of population served after anaerobic digestion of sludge from conventional activated sludge plants upgraded for total phosphorus removal to 1.0 $mg \cdot L^{-1}$.

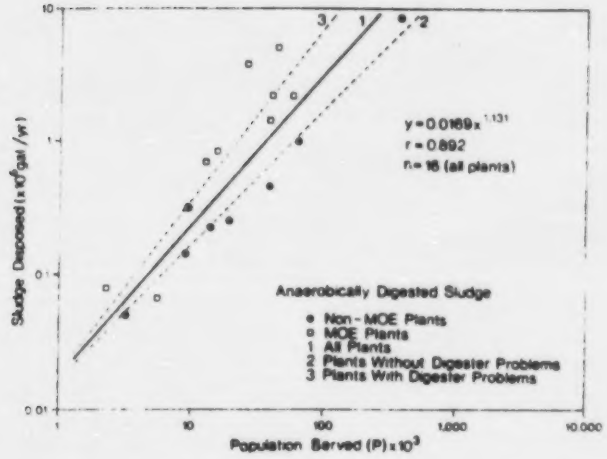
Sludge Disposed (x 10⁶ gal /yr)
Population Served (P) x 10³
y = 0.0169 x^1.131
r = 0.892
n = 16 (all plants)
Anaerobically Digested Sludge
• Non-MOE Plants
o MOE Plants
1 All Plants
2 Plants Without Digester Problems
3 Plants With Digester Problems

FIGURE 18. SLUDGE VOLUME DISPOSED AT CONVENTIONAL PRIMARY PLANTS (3)

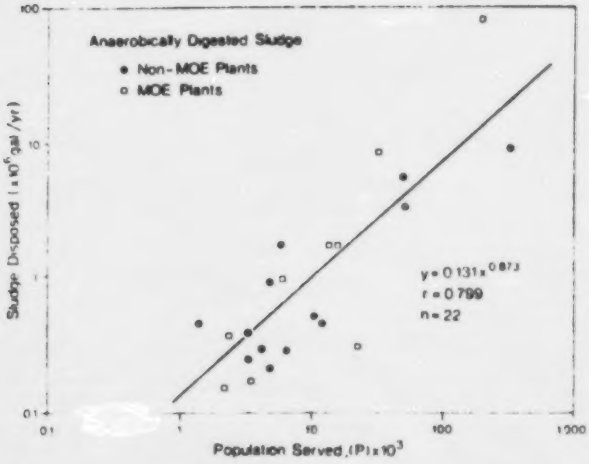

FIGURE 19. SLUDGE VOLUME DISPOSED AT CONVENTIONAL A.S. PLANTS (3)

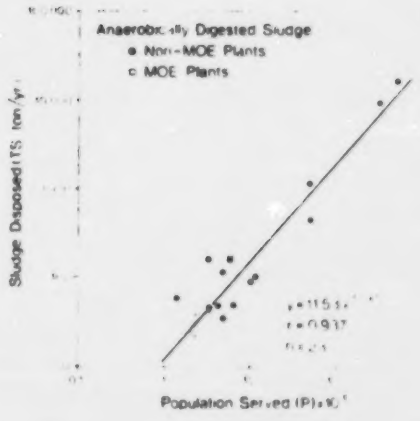

FIGURE 20. SLUDGE MASS DISPOSED AT CONVENTIONAL A.S. PLANTS (3)

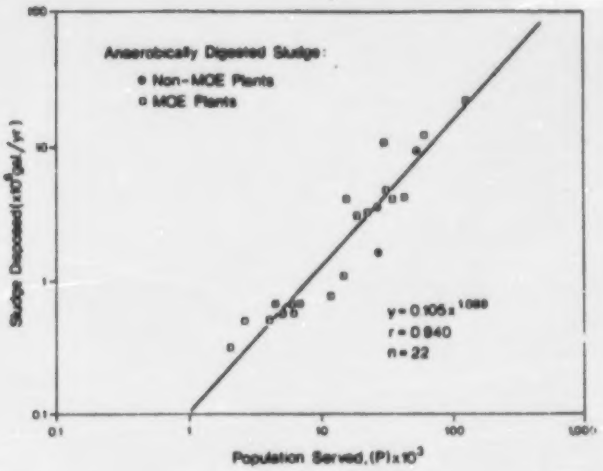

FIGURE 21. SLUDGE VOLUME DISPOSED AT CONVENTIONAL A.S. PLANTS UPGRADED FOR P REMOVAL TO 1 $mg \cdot L^{-1}$

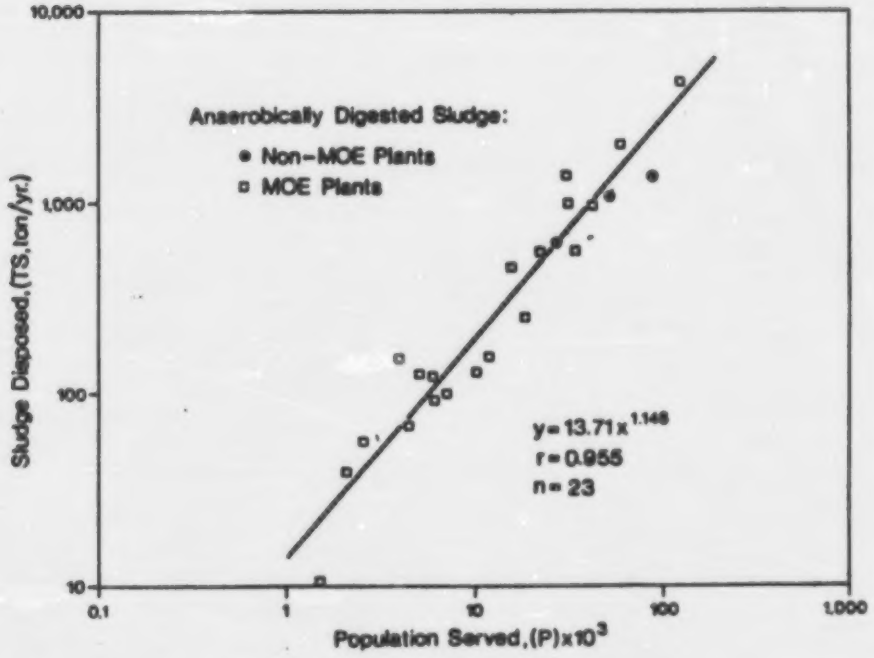

FIGURE 22. SLUDGE MASS DISPOSED AT CONVENTIONAL A.S. PLANTS UPGRADED FOR P REMOVAL TO 1 $mg \cdot L^{-1}$ (3)

The equations for the various functions shown in Figures 19 to 22 are summarized in Table 5.

TABLE 5. SUMMARY OF ANAEROBICALLY DIGESTED SLUDGE DISPOSAL-RELATIONSHIPS WITH POPULATION SERVED (3)

Standard C.A.S. Plants		
n = 22	Sludge disposed = 0.131 (Population x 10^{-3})$^{0.873}$ ($\times 10^6$ gal·yr^{-1})	(6)
n = 23	Sludge disposed = 11.53 (Population x 10^{-3})$^{1.097}$ (TS, ton·yr^{-1})	(7)
Upgraded C.A.S. Plants		
n = 22	Sludge disposed = 0.105 (Population x 10^{-3})$^{1.089}$ ($\times 10^6$ gal·yr^{-1})	(8)
n = 23	Sludge disposed = 13.71 (Population x 10^{-3})$^{1.146}$ (TS, ton·yr^{-1})	(9)

4. SUMMARY - SUGGESTED DESIGN DATA

Based on the results of the Ontario survey (3), some generalizations concerning sludge production design data are shown in Table 6.

4.1 Sludge Quantities Prior to Anaerobic Digestion

TABLE 6. SLUDGE PRODUCTION - SUGGESTED DESIGN DATA*

	Plant Type	Sludge Quantity		
		lbs pcd	Volume % of influent	lbs d.s./10^6 gal
Primary	Conventional	0.17	0.20	1 200
	Upgraded	0.24	0.32	1 700
STD.A.S.	Conventional**	0.25	0.38	1 725
	Upgraded**	0.32	0.51	2 170

* based on Q = 145 gpcd
d.s. = dry solids
pcd = per capital/day
** primary + waste activated

The rule-of-thumb that sludge volume approaches 0.5% of the influent hydraulic load to a conventional plant is a good approximation. By using this estimate, the apparent margin of safety would allow upgrading of a conventional plant to include chemical phosphorus removal to 1.0 $mg \cdot L^{-1}$ total phosphorus using metal salts without major expansion of sludge handling facilities.

4.2 Sludge Quantities After Anaerobic Digestion

Figure 23 summarizes all the pertinent water pollution control plant data from the Ontario survey (3). More specifically those data illustrate that in Ontarios' case anaerobic digestion will reduce the total solids generated by as much as 50% on the average. When phosphorus removal to 1.0 $mg \cdot L^{-1}$ is practised anaerobic digestion will reduce the total solids by 44% on the average.

The data for anaerobic digestion of solids from Ontario conventional activated sludge treatment facilities show that on average a total solids reduction of 43% is achieved. With simultaneous chemical addition for phosphorus removal to 1.0 $mg \cdot L^{-1}$ this drops to an approximate 40% reduction in total solids after anaerobic digestion.

These data are within the range of 25 - 58% TS reduction normally found in the literature (10).

5. CONCLUSIONS

1. Sludge production estimates based on stoichiometric relationships can fluctuate by at least $\pm$50 percent. The rule-of-thumb that for biological treatment plants using metal salt addition for phosphorus removal 0.5% of the influent wastewater winds up as sludge is supported by data from the Ontario survey.

2. Metal salt addition for phosphorus removal to 1.0 $mg \cdot L^{-1}$ total phosphorus at primary and secondary activated sludge plants has increased sludge volumes by 60 and 35 percent, respectively.

3. Lime treatment of municipal sewage to total phosphorus concentrations of < 0.1 $mg \cdot L^{-1}$ can result in sludge volumes up to 700 percent greater than normally experienced.

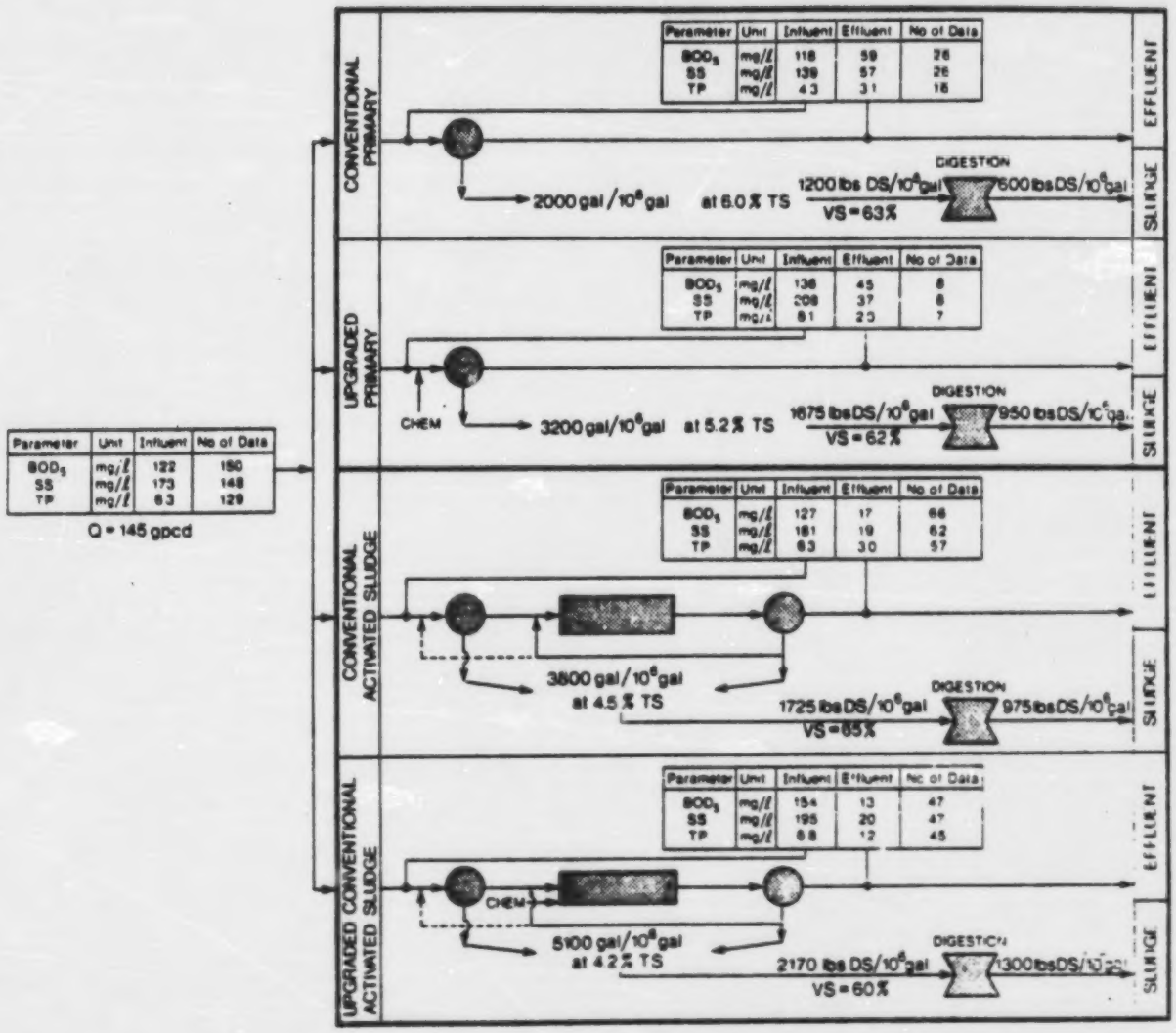
Parameter | Unit | Influent | No of Data
BOD5 | mg/ℓ | 122 | 150
SS | mg/ℓ | 173 | 148
TP | mg/ℓ | 63 | 129
Q = 145 gpcd
CONVENTIONAL PRIMARY
Parameter | Unit | Influent | Effluent | No of Data
BOD5 | mg/ℓ | 118 | 59 | 26
SS | mg/ℓ | 139 | 57 | 26
TP | mg/ℓ | 43 | 31 | 16
2000 gal/10^6 gal at 6.0 % TS
DIGESTION
1200 lbs DS/10^6 gal
600 lbs DS/10^6 gal
VS = 63%
EFFLUENT
SLUDGE
UPGRADED PRIMARY
Parameter | Unit | Influent | Effluent | No of Data
BOD5 | mg/ℓ | 136 | 45 | 8
SS | mg/ℓ | 208 | 37 | 8
TP | mg/ℓ | 81 | 23 | 7
CHEM
3200 gal/10^6 gal at 5.2 % TS
DIGESTION
1675 lbs DS/10^6 gal
950 lbs DS/10^6 gal
VS = 62%
EFFLUENT
SLUDGE
CONVENTIONAL ACTIVATED SLUDGE
Parameter | Unit | Influent | Effluent | No of Data
BOD5 | mg/ℓ | 127 | 17 | 66
SS | mg/ℓ | 181 | 19 | 62
TP | mg/ℓ | 63 | 30 | 57
3800 gal/10^6 gal at 4.5 % TS
DIGESTION
1725 lbs DS/10^6 gal
975 lbs DS/10^6 gal
VS = 65%
EFFLUENT
SLUDGE
UPGRADED CONVENTIONAL ACTIVATED SLUDGE
Parameter | Unit | Influent | Effluent | No of Data
BOD5 | mg/ℓ | 154 | 13 | 47
SS | mg/ℓ | 195 | 20 | 47
TP | mg/ℓ | 68 | 12 | 45
CHEM
5100 gal/10^6 gal at 4.2 % TS
DIGESTION
2170 lbs DS/10^6 gal
1300 lbs DS/10^6 gal
VS = 60%
EFFLUENT
SLUDGE

FIGURE 23. SUMMARY OF ONTARIO WATER POLLUTION CONTROL PLANT SLUDGE PRODUCTION AND DISPOSAL DATA (3)

Insofar as sludge production data for conventional and upgraded primary and activated sludge plants are concerned, this can best be summarized as shown in Table 7 for the cases of before and after anaerobic digestion.

TABLE 7. SLUDGE QUANTITIES SUMMARY

Plant Type		Anaerobic Digestion (lbspcd)	
		before	after
Primary	Conventional	0.17	0.09
	Upgraded	0.24	0.14
STD.A.S.	Conventional	0.25	0.14
	Upgraded	0.32	0.19

Clearly properly designed and well operating anaerobic digestion facilities will greatly reduce the sludge quantity which requires ultimate disposal.

As well, with todays escalating energy costs, the opportunity for energy recovery and reuse at water pollution control facilities cannot be neglected in the design of sludge handling, treatment and disposal/utilization facilities.

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SLUDGE APPLICATION TO LAND - HEALTH IMPLICATIONS

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SLUDGE APPLICATION TO LAND
— HEALTH IMPLICATIONS

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Canadian sewage treatment plants produce hundreds of tons of sludge per day which requires disposal. This sludge will contain nutrients beneficial to the growth of crops and the consumers of these crops. However, it may also contain biological and chemical agents capable of producing disease, either directly or indirectly in humans. It is to these two groups of agents that I wish to address myself.

I hope to delineate and where possible to quantify the risk. It is realized, however, that there are many other factors which must be considered. Amongst these being the effect on the vegetation growing in the area and animals feeding on such vegetation. Occasional references may be made to these.

CHEMICAL AGENTS

It is intended to limit our discussion in this section to:

I. Heavy Metals
II. Synthetic Organic Compounds

which may spread from sludge when applied to land to humans and cause disease. Other chemicals certainly influence human health such as nutrients and salts, but generally for the good. A few such as nitrites and nitrates may cause disease.

While in theory chemicals could reach man directly from sludge, in practice the danger lies in the indirect spread. The principle means being:

1. an accumulation in edible plants
2. drinking water
3. surface waters

I. HEAVY METALS

Almost any heavy metal may find its way into municipal sludge. The type and concentration will largely depend on the number and diversity of the industries hooked up to the system.

1. EDIBLE PLANT UPTAKE

The uptake of heavy metals will depend on:

1. the type of plant
2. soil type especially ph
3. metal content of sludge
4. rate of sludge applications

They can be divided into three groups depending on their toxicity to plants, lower animals and humans.

A. POSING LITTLE HAZARD TO PLANTS AND ANIMALS

Amongst this group are: maganese, iron, aluminium, chromium, arsenic, selenium, antimony and lead. These pose little hazard to either plants for those who eat the plants.

This is either because of their low solubility or because they are present in such small amounts in the sludge. As a result the availability of these elements to the plants is relatively low and little uptake by plants occurs.

B. ELEMENTS POSING A SERIOUS HAZARD TO PLANTS AND/OR LOWER ANIMALS

This includes:

1. COPPER

This has been found in sludges in concentrations of 50 - 11,000 ppm. The uptake by plants is highly variable dependent on the species. Whereas little is taken up by potatoes when sludge with high copper uptake is applied to the land,vegetables such as cucumber and brocolli have high uptakes.

Copper toxicity may develop in plants when the copper content of the sludge is high and this occurs before levels are reached in edible plants which will harm man. Thus man is protected from harm by this source by the phytotoxicity of the metal.

Sheep are the most susceptible of the lower animals, followed by cattle, swine and poultry in that order. The effect, however, seems to be related to the availability of molybdenum and ruminants can ingest this concentration of copper if sufficient molybdenum is available. It should be pointed out that levels of 250 ppm in the diet are necessary for optimum levels of health in pigs and high levels are also required by chickens.

2. MOLYBDENUM

Molybdenum has been found in concentrations of up to 100 ppm in sludge. In general the concentrations are very low. It is required in

small amounts by plants and is concentrated by them. It does not appear to be toxic to plants even at a few hundred ppm in plant tissues. It is not harmful to humans at this level. However, at levels of 10 - 20 ppm in plants it may produce molybdenosis in ruminants but this problem would arise only under exceptional circumstances because of low levels of molybdenum in sludge.

3. NICKEL

Nickel has no essential function in plants. It is toxic to them at concentrations of over 50 ppm of plant tissues and at these levels poses no problems when ingested by humans.

4. ZINC

Zinc is essential for plants and animals. Addition of sludge high in zinc will substantially increase the zinc content of the plants. Levels usually attained are not harmful to plants unless exceptionally high levels are added to sludge. Phytotoxicity is cited by several authors as a safeguard against human disease.

C. ELEMENTS POSING A THREAT TO HUMANS

Cadmium is the only metal which need be included in this group. Cadmium is included in this section because:

1. It is present in significant concentrations in many municipal sludges.
2. It is appreciably absorbed, translocated and accumulated by certain human food crops in particular green leafy vegetables.
3. It is accumulated by the human kidney, the target organ of concern.
4. In increment intake above current averages and the point of discernable effect is narrow when compared to those in Group B.

With very high intake of cadmium, cadmium poisoning has occurred in Japan. They gave the name to the disease occurring "Itai-Itai Disease" which translated means Ouch-Ouch.[1] This was because of the extreme sensitivity to touch. This disease is characterized by lumbar pains, leg myalgia, duck-like gait as well as bone tenderness. Levels are not reached in elible plants which will give this type of disease.

In humans or animals who have had exposure to cadmium at lower levels over a prolonged period, renal tubular damage has occurred.[2] Evidence from animal experiments and from analysis of cadmium in the kidneys of workers exposed to cadmium indicate that renal tubular dysfunction may become manifest at levels around 200 µg/G wet weight of renal cortex. In calcium deficient animals this may be even lower.

With respect to other disease, while evidence is available that cadmium when injected into rats can cause malignant tumors at the site of

injection,[3] there is not evidence that it is carcinogenic to humans by injection, ingestion or inhalation.

Very few genetic studies[3] have been performed and the results are contradictory.

The evidence that chronic exposure to cadmium cause hypertension[4] is not convincing. In humans who have died after a history of hypertensive disease, some studies show cadmium levels in kidney tissue higher than in people who have died from other disease. Whether the high cadmium levels are the cause or the effect of the hypertension is unknown. Epidemiological investigations have indicated a relationship between cadmium levels in the air and cardiovascular disease. There is reason to believe that the association is spurious and in any case no causal association has been proven.

As mentioned before, the critical level to avoid would appear to be 200 µg/G of wet kidney. This can be reached with a 50 year intake of 250 µg - 350 µg/day assuming an excretion of 0.005% - 0.01%/day of total body burden of cadmium. One other author, Lucas[5], gave a slightly higher level of 440 µg/day. He postulated that in order to give a sufficient degree of protection to allow for variables in the human population, we should aim at an intake of less than 110 µg/day. W.H.O. suggests 50 - 70 per day. The average person consumes 2,200 G/day of food. Thus the average concentration of cadmium in the food must be less than 50 ppB. Out of the food classes he examined for cadmium content, potatoes (48 ppm) and leafy vegetables (40 ppB) were close to this limit. However, the average intake by any person is in the order of 33 µg/day with an intake of 40 µg in the 15 - 19 year olds. Therefore vegetarians or persons with abnormally skewed dietary habits have little leeway.

The author, after a long mathematical computation, concludes that if a person eats a normal diet and uses municipal sludge to amend the soil where practically all his food is grown it would be prudent to assume that such sludge contain less than 60 ppm cadmium at a near neutral ph. However, he goes on to point out that it is unlikely that a person will remain in the same area all his life and eat vegetables produced from one particular piece of land. The levels suggested by some authorities are as low as 15 ppm per year.

Chaney[6] has suggested the following maximum levels of heavy metal in sludge:

Table 1: SUGGESTED MAXIMUM HEAVY METAL CONCENTRATIONS IN SLUDGE

METAL	MAXIMUM CONCENTRATION (mg/kg)
Zn	2,000
Cu	1,000
Ni	200
Cd	15 or 1% of Zn
Pb	1,000
Hg	10
Cr	1,000
B	100

These levels are often under the mean levels attained in North American sludges and would appear to be conservative.

2. DRINKING WATER

The concern here is that heavy metals in the sludge will migrate through the soil into the human water supplies.

This will depend on the location of the disposal site in relation to wells and the topography and geology of the ground. In limestone areas there may be fissures which could carry liquids long distances.

Riekerk and Zasoski[7] have looked at this problem. They added sludge with a known concentration of zinc, lead, nickel, copper, and cadmium to gravelly soil. Analysis of ground water collected from a well which intercepted ground water at a depth of ten meters under the treatment area showed no detectable increase above background heavy metal concentrations. Absorption of metals was high in the first 10cm but as the results show below (Table 2) little or no mobility is evident. Below that only very high sludge application rate (25cm) resulted in limited amounts of zinc in the subsoil.

Table 2: METALS EXTRACTED FROM GRAVELLY SOIL (2mm FRACTION) BY 2N HCl AFTER SLUDGE ADDITIONS

TREATMENT	HORIZON	DEPTH (cm)	METAL CONCENTRATION (PPM) Zn	Pb	Ni	Cu	Cu
Sludge*	-	-	2000.0	1200.0	120.0	700.0	50.0
Control	A	10	21.8	9.8	1.4	5.4	0.13
	B	60	1.6	2.3	0.28	6.1	<0.1
	C	170	5.8	2.2	1.33	7.9	<0.1
10cm Spread	A	10	622.0	63.4	35.9	439.0	14.2
	B	60	3.8	4.2	0.32	6.0	<0.1
	C	170	2.8	3.4	1.65	8.2	0.1
10cm Disked	A	10	450.0	66.0	25.0	214.0	13.0
	B	60	4.5	3.1	0.28	5.8	<0.1
	C	170	3.6	3.1	1.47	8.7	<0.1
25cm Spread	A	10	63.0	7.5	4.6	11.1	0.58
	B	60	11.6	5.0	0.7	6.7	<0.1
	C	170	6.4	3.9	1.7	8.2	<0.1

*An average value for nitric-perchloric digest of fresh sludge delivered to Pack Forest.

It would appear from the above that a distance of 30 meters would more than adequately protect water supplies.

3. SURFACE WATER

Surface water contamination can be prevented by applying sludge:

1. to fairly level surfaces
2. fairly far from water courses
3. to areas not susceptible to flooding.

In the flow of leachate over the land it is probable that there will be little reduction in metal content. Thus our aim should be to prevent the leachate reaching the surface water by an overland route.

Bell[6] has suggested the minimum distance between water courses and sludge application for a number of slopes and two seasons (see Table 3).

Table 3: MAXIMUM SUSTAINED SLOPE VS MINIMUM DISTANCE TO WATERCOURSES (BELL, 1971)

MAXIMUM SUSTAINED SLOPE	MINIMUM DISTANCE TO WATERCOURSE FOR SLUDGE APPLICATION DURING MAY TO NOV., INCLUSIVE	MINIMUM DISTANCE TO WATERCOURSE FOR SLUDGE APPLICATION DURING DEC. TO APR., INCLUSIVE
0 to 3%	200 ft	600 ft
3 to 6%	400 ft	600 ft
6 to 9%	600 ft	No sludge to be applied
Greater than 9%	No sludge to be applied unless special conditions exist	No sludge to be applied

In the above criteria are level it is reasonable to expect that sludge application will not affect the potability of the well water or surface water.

II. SYNTHETIC ORGANIC COMPOUNDS

Sludge may contain certain persistent synthetic organic compounds which are potentially dangerous to public health. These are polychlorinated biphenyls (P.C.B.) and organic insecticides.

Polychlorinated biphenyls have been reported in sludge in levels up

to 450 µg/kg.[9] They have been shown to cause acneiform lesions, liver cancer in animals, gastric disorders, discharges from the eye and hyperpigmentation with intakes as low as 67 µg/kg/day over a three month period.[9]

Biomagnification[9] in fish and animals has been observed with P.C.B.'s and organic insecticides as high as 2.7×10^{14}. This biomagnification has not been noted in plants.

The danger with sludge containing these synthetic organic compounds lies in:

1. There must be limits to the PCB concentration in sludge used on land where it is used for grazing by milk cows and animals used as a meat source for humans. One report showed cows' milk to contain 5 ppm of PCBs on a fat basis (twice the F.D.A. standard).
2. Dumping of sludge into the ocean. This is unacceptable unless the sludge can be shown to have sufficiently low levels of these.
3. The leaching or surface spread of these elements into drinking water supplies or water containing fish used for human consumption. This must be avoided by separating disposal sites sufficiently far from the water and by choosing a site with satisfactory topography.

The U.S.A. has set the following maximum contaminant levels for organic chemicals in water:

Table 4: MAXIMUM CONTAMINANT LEVELS FOR ORGANIC CHEMICALS IN WATER SET BY THE U.S.A.

METAL	LEVEL (mg/litre)
Chlorinated Hydrocarbon	
Endrin	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.0005
Chlorophenoxy	
2, 4-D	0.1
2, 4, 5-TP	0.01
Chlorinated Biphenyls	0.001

It is likely that a distance of greater than 30 meters between the sludge disposal site and a well used as a source of drinking water will be sufficient to maintain safe levels of these compounds.

BIOLOGICAL AGENTS

These can be divided into four groups:

1. virus
2. bacteria
3. protozoa
4. helminths and their ova

Table 5 shows the major organisms of health concern that may be present in sludge in Canadian communities.

Table 5: MAJOR ORGANISMS OF HEALTH CONCERN THAT MAY BE PRESENT IN SEWAGE FROM CANADIAN COMMUNITIES

ORGANISMS	DISEASE	RESERVOIR(S)
I. BACTERIA		
Salmonellae (approx. 1700 types)	Typhoid Fever Salmonellosis	Man, domestic and wild animals and birds
Shigellae (4 spp)	Shigellosis (bacillary dysentary)	Man
Escherichie coli (enteropathogenic types)	Gastroenteritis	Man, domestic animals
II. ENTERIC VIRUSES		
Enteroviruses	Gastroenteritis, heart anomalies, meningitis others	Man, possibly lower animals
Rotavirus	Gastroenteritis	Man, domestic animals
Parvovirus-like agents (at least two types)	Gastroenteritis	Man
Hepatitis A virus	Infectious Hepatitis	Man, other primates
Adenoviruses	Respiratory disease conjunctivitis, other	Man
III. PROTOZOAN		
Balantidium	Balantidiasis	Man, swine
Entamoeba histolytica	Amebiasis	Man
Giardia Lambia	Giardiasis	Man, domestic and wild animals

Table 5 (cont'd)

ORGANISMS	DISEASE	RESERVOIR(S)
IV. HELMINTHS		
Nematodes (roundworms) Ascaris lumbriccides	Ascariasis	Man, swine?
Ancylostoma duodenale	Ancylostomiasis	Man
Necator americanus	Necatoriasis	Man
Enterobius vermicularis	Enterobiasis	Man
Strongyloides stercoralis	Strongyloidiasis	Man
Toxocara cati	Visceral Larva Migrans	Carnivores
Trichuris trichiura	Trichuriasis	Man
Cestodes (tapeworms)		
Taenia saginata	Taeniasis	Man
Taenia solium	Taeniasis	Man
Hymenolepis nana	Taeniasis	Man, rat
Echinococcus granulosus	Unilocular Echinococcosis	Dog
Echinococcus multilocularie	Alveolar Hydatid	Dog, carnivores

The type and concentration of organisms will depend on the type and number of infections occurring in the community where the organisms are excreted in the feces or urine. This may vary from zero to very large numbers.

In a study by Malina[13], he found 71% - 97% of the virus in the raw wastewater associated with the sludge. Other studies have shown a similar figure for bacteria.[13]

Protozoan helminths and their eggs tend to migrate even more to the sludge. Liebmann[8] suggested that worm eggs having a specific gravity of 1.1 or greater will sediment at a rate of 2 - 3 ft/hr and thus two hours of sedimentation is sufficient to remove all eggs from the supernatent into the sludge.

With respect to the production of disease in humans, the most critical point is the number of organisms taken into the body and whether this exceeds the minimal infectious dose. This minimal infectious dose varies with the organisms, but in general we can say that as little as one virus, ten bacteria in the case of bacillary dysentary and one protozoa may cause disease in susceptible humans. However, particularly with bacteria, millions of organisms may be required to initiate infection.

The number of viable organisms taken in the body will depend on many factors. We will discuss the following which, while not being an exhaustive list, we think the most important.

1. SLUDGE TREATMENT METHODS

   A. Heat - Mesophilic
            - Thermophilic

   B. Composting

   C. Drying

2. SITE SELECTION AND ITS ASSOCIATION WITH POTENTIAL VECTORS

   A. Distance from wells

   B. Surface contamination of drinking water supplies and primary contact recreational waters

   C. Sludge infecting humans via lower animal infection

   D. Recreational use of land

   E. Vegetables and other foods in direct contact with sludge

It should be pointed out that very few incidences of disease transmission have been traced to sludge disposal activities, however many have been traced to the use of sewage polluted irrigation waters. It is difficult to reconcile these two findings although it would seem that the difference lies in the infrequent use of sludge in North America compared to the use of sewage contaminated irrigation waters.

TREATMENT METHODS

1. HEAT

In the survival of organisms heat, together with time are the most important factors in biological stabilization whether it be anaerobic or aerobic digestion. Two distinct temperature ranges of digestion are usually required:

Mesophilic: $92^{\circ} - 98^{\circ}F$ or $33^{\circ} - 37^{\circ}C$

Thermophilic: $105^{\circ} - 110^{\circ}F$ or $40^{\circ} - 43^{\circ}C$

Other factors such as food, ph, and time must be controlled.

You will note from Table 6 that temperatures in the 55°C range and up are lethal to organisms within one hour, however as the temperature gets lower the efficiency of killing organisms is lower.

Table 6: DESTRUCTION OF SOME COMMON PATHOGENS AND PARASITES*

ORGANISM	OBSERVATIONS
Salmonella typhosa	No growth beyond 46°C; death within 30 min. at 55°-60°C and within 20 min. at 60°C; destroyed in a short time in compost environment
Salmonella Sp.	Death within 1 hr. at 55°C and within 15-20 min. at 60°C
Shigella Sp.	Death within 1 hr. at 55°C
Escherichia coli	Most die within 1 hr. at 55°C and within 15-20 min. at 60°C
Entamoeba histolytica cysts	Death within a few min. at 45°C and within a few seconds at 55°C
Taenia Saginata	Death within a few minutes at 55°C
Trichinella spiralis larvae	Quickly killed at 55°C; instantly killed at 60°C
Mycobacterium tuberculosis var. hominis	Death within 15-20 min. at 66°C or after momentary heating at 67°C
Necator americanus	Death within 50 min. at 45°C
Ascaris lumbricoides eggs	Death in less than 1 hr. at temperatures over 50°C

* From Golueke, C.G. (1972)
Composting (Emmanus, P.A.: Rosedale Press Inc.)

Berg compared the effectiveness of mesophilic with thermophilic digestion (see Table 7).

Table 7: DESTRUCTION OF VIRUS IN RAW SLUDGE BY MESOPHILIC AND THERMOPHILIC DIGESTION FOR 20 MINUTES*

TEST NO.	SLUDGE PFU/100 ML RAW	MESOPHILICALLY DIGESTED	% REDUCTION	THERMOPHICALLY DIGESTED	% REDUCTION
1	550	50	91%	<3.1	>99.4%
2	2,780	280	90%	3.3	99.9%
3	1,810	100	95%	1.7	99.9%
4	1,500	360	76%	16.7	98.9%

*Modified from Berg, G., "Viruses in the Environment - Criteria for Risk", Proceedings of the Conference on Risk Assessment and Health Effects of Land Application of Municipal Waste Waters and Sludges, ed: Sagik, B.P. and Sorber, C.A. December 1977

Grigor'eva[18] found that an autoclave of sludge which had E. coli (10,000/ml) and coliphage (10,000/ml) added that with mesophilic temperatures E. coli survived two months and coliphage four months, however at thermophilic temperatures the coliforms survive only five hours and the coliphage eleven days.

Lessel et al.[19] cites evidence that digestion of sludge at 32°C for 20 days is not sufficient for destruction of pathogens to permissible levels. They claim that 10^6 - 10^7 salmonella can be found per litre of sludge digested at this temperature.

Palfi[20] showed only a 95% reduction in virus with digestion at 33°C for forty days.

Sanders[21] investigating the effect of temperature and time on Polio 1 concentrations in sludge found a 4 $\log_{10}$ reduction in virus in ten days at 37°C, and 3 $\log_{10}$ in ten days at 34°C.

Wiley[22] showed that complete inactivation of S. Newport was attained in forty minutes at 60°C, Poliomyelitis at 55°C in thirty minutes, and Ascaris ova at 60°C in sixty minutes.

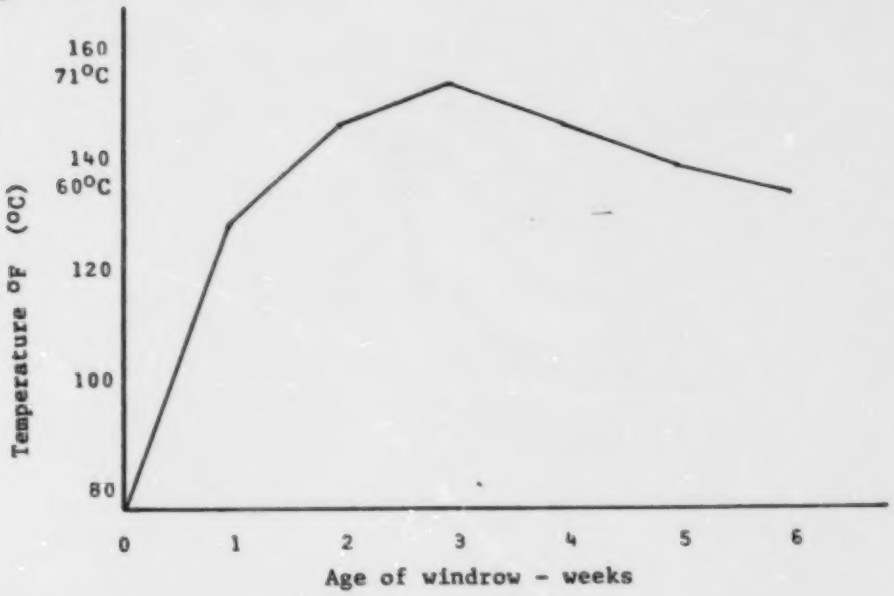
Fitzgerald[23] showed that Ascaris Lumbricoides Suum ova held at 38°C for twenty-five days in sludge failed to embryonate in the sludge but after removal and exposure to air and 1% formalan the ova embryonated.

From Table 6 is would appear that mesophilic temperatures for 20 - 30 days is not very effective in reducing the microbiological content. On the other hand, thermophilic temperatures for 20 - 30 days would certainly appear to be effective against bacteria, virus, protozoa and helminths.

COMPOSTING

This is an aerobic biological method of sludge stabilization mixing dewatered sludge with a bulking agent such as bark mulch. A temperature of 60 - 70°C may be reached in two weeks (see Figure 1).

Figure 1:



From: Fig 3-7 Treatment and Disposal of Wastewater Sludges
Ed: Vesilind, P.A., Ann Arbor Science

As indicated in Table 6, such a temperature even for a few hours is capable killing pathogenic organisms.

However, Kawata[24] monitoring coliforms, faecal Coliform, and Salmonella occurring naturally in sludge through the windrow and stockpile phases of composting did not get anything like as good results as we would expect in theory. Salmonella declined to undetectable levels after 20 days. Seeded bacteriophage (f2) 10^6 P.F.U./Gram declined to undectable levels in 50 days for raw sludge and 50 - 70 days for digestive sludge.

Nevertheless it would appear that composting if carried out for a minimum of two months, and preferably six, where temperatures of 60°C + are attained in the center of the windrow, is a most effective way of reducing the microbes to a safe level.

C. DRYING

Not much information is available on this, however Bryan[16] has drawn together information on survival of a variety of organisms in soil. He quotes the long survival for the organisms as:

a)	Salmonella typhii:	120 days
b)	Salmonella:	>280 days
c)	Strep Faecalis:	77 days
d)	Endamoeba Histolytica:	68 days
e)	Ascaris ova:	1,190 days

It would seem that with the exception of Ascaris ova that organisms would not survive one year using drying alone.

SITE SELECTION

1. WELLS

Many studies have been carried out in the field and in the laboratory to assess the spread of organisms through soil.

Gilbert[25] assessed the spread of virus, Salmonella and indicator organisms from secondary sewage effluent flooded on ground to surrounding wells. He found that Faecal Coliforms, Faecal Strep decreased by 99.9% and virus greater than 99.99% after filtering 9 meters of soil.

Vaughan[26] investigated the spread of organisms from three sewage recharge installations to ground water observation wells. He found virus at 18 - 34 feet (vertical) level but the virus was unable to penetrate the 80 foot depth of the recharge basin.

It would appear that in the absence of a fault in rock that a distance of thirty meters between sludge application and a well is sufficient to reduce microbial content to zero.

2. SURFACE RUN-OFF

It is observed that the topography of the disposal site must be such that there will be no run off to surface waters as one would expect a limited die off in the run off period.

3. LOWER ANIMALS

The animals of concern are farm animals such as cattle, pigs, and sheep. The danger is that these animals will become infected by the sewage contaminated grass or sewage contaminated fodder and through ingestion of the meat or other means infect humans.

The number of diseases involved is relatively small. No virus excreted by humans in the faeces or urine causes disease in these animals. The organisms of concern are:

Salmonella (excluding S. typhii and S. Paratyphii A.B.)
Taenia Saginata
Taenia Solium

SALMONELLA

Salmonella is an organism that infects all warm blooded animals. It is likely that inadequately heated sludge will contain Salmonella and thus infect grazing animals. This as well as producing potential disease in the animals may lead to contamination of the meat and subsequently infection of humans when consumed.

Salmonella is a common human infection. Some have estimated that one per cent of the population is affected in any one year.

Dean and Jones showed 9,300 Salmonella/100 ml in raw sludge and 29/100 ml in anaerobically digested sludge. Others have shown levels of up to one million per hundred ml.

The salmonella organism is not very infectious in that at least one million organisms are required to initiate infection through ingestion in all animals . Thus assuming no die off in organisms in the applied sludge before digestion and using Dean and Jones' figures, ten litres of raw sewage or 300 or digested sludge must be consumed.

TAENIA SAGINATA

The life cycle of this parasite is relatively simple. In man the tapeworm lives in intestinal tract and discharges eggs in the faeces of the host. Cattle ingest these eggs through faecal contaminated feed. The eggs hatch in the intestine of the cattle and migrate to muscle tissue (thus the name "Measly Beef"). Man becomes infected when he eats raw or inadequately cooked beef. The organism grows to an adult tapeworm in the human intestinal tract and the cycle is complete.

Taenia Saginata is not a common infection in B.C. Only 212 isolates of Taenia Saginata and its cousin Taenia Solium (pig tapeworm) were found in British Columbia in twenty years (1956 - 1975) i.e. about ten cases per year.[24] Therefore it is unlikely that raw B.C. sludge will contain many eggs.

Chloramines are very poor in killing ova.

Vassilkova[30,34] reports only a 20% reduction in viable eggs after digestion and Newton reports 10 - 15% of eggs remain viable after 200 days digestion.

Jepsen and Roth[33] in a cattle feeding experiment studied the survival of tapeworm eggs on grass. They survived 159 days on average with survival depending on temperatures and the degree of drying.

Taenia solium, the pork tapeworm, is a more serious disease for humans than T. Saginata. This organism as well as having a cycle where the adult tapeworm if found in the human gut, has also a cycle where the larva migrate to the human brain, heart, and eye, as well as other organs and cause severe health problems.

The safety precautions discussed with T. Saginata also apply to T. Solium.

It would appear that useful guidelines for the grazing of cattle on land which had sludge applied would be:

1. No Digestion
   - wait one year
   - Ascaris ova are the only organism which exceed this but they do not infect cattle.
2. Mesophilically
   - wait one month
3. Thermophilically - 60°C for 10 days
   - no waiting necessary

D. RECREATIONAL USE

It would appear reasonable that:

1. After raw sludge is spread you wait two years before it is used by the public because of the Ascaris ova.
2. Mesophilic digestion you wait one year.
3. Thermophilic digestion wait 0 - 2 months depending on temperature reached.
4. Composting no wait.

VEGETABLES

Mesophilically digested sludge may contain pathogenic organisms. These organisms when applied directly to vegetables may live for many days.

Bryan[6] has drawn together information from fourteen references on the survival of enteric pathogens on food (see Table 7). Many of these survival times are longer than the growing period of the vegetables. Thus it must be concluded that when the vegetables are being eaten raw or lightly cooked human infection may occur.

Table 7: SURVIVAL OF ENTERIC PATHOGENS ON FOODS

PATHOGEN	VEGETABLE	SURVIVAL (in days)
Salmonella typhii	Vegetables (leaves and stems)	10 - 31
	Radishes	28 - 53
	Lettuce	18 - 21
Salmonellae	Vegetables	40
	Vegetables	28
	Beet leaves	21
	Tomatoes (laboratory)	20
	Tomatoes (field)	3
	Soil and potatoes	>40
	Carrots	>10
	Cabbage & gooseberries	> 5
	Tomatoes	3
Shigella sonnei and S. flexneri	Clams and shrimp	>60
	Oysters	>40
S. sonnei	Tomato (surface)	2
	Tomato (tissue)	10
	Apple (skin)	8
Vibrio chlorae	Vegetables	5
	Dates	<1 - 3
	Shellfish	20 - 45
	Vegetables	7
	Vegetables (refrigerated)	<14
Endamoeba histolytica	Lettuce and tomatoes	< 3
Ascaris ova	Lettuce and tomatoes	27 - 35

This could be avoided if the sludge were adequately heated during treatment, such as is attained by composting, i.e. or the vegetables were cooked at 70°C. However despite the above, it is my feeling that unless we can guarantee that there will be no processing errors, sludge should not be used in vegetables for human consumption. With fruit trees where the sludge does not touch the fruit there is no danger since organisms are not translocated from soil to the fruit via the tree. Vegetables can be grown on land after 18 months where sludge which has had mesophillic digestion has been spread.

IN SUMMARY

Sludge in British Columbia may contain chemical and biological agents capable of causing human disease.

Exposure of humans to these agents will depend on the degree of treatment given to the sludge, and method of disposal and the type of vector associated with the method of disposal.

The only chemical of concern to human health is cadmium. Biological agents can be killed with adequate heat and/or time, treatment such as may be attained with composting.

Sludge should not be used on vegetables for human consumption unless it can be guaranteed that there will be no errors in the processing of a safe sludge or in cooking vegetables.

Land which has had sludge applied can be used to graze animals and for human use depending on the type of treatment used.

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LYSIMETER AND FIELD STUDIES ON LAND APPLICATION OF WASTEWATER SLUDGES

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ABSTRACT

Lysimeter studies at Burlington, Ontario and field studies at Guelph, Ontario, were undertaken in 1973 and 1974 to determine the effects on crop yield and quality and on groundwater quality of land application of sludges containing Al, Fe and Ca added to remove phosphorus from wastewater. Similar results were obtained from the lysimeter and field experiments. Orchard grass, bromegrass, wheat and corn yields with sewage sludge were as large as, or larger than, with commercial fertilizer and there were no consistent differences between yields from the Al, Fe and Ca sludge treatments. There was no evidence of yield reduction even from the highest rates of sludge application which ranged up to 499 tonnes $\cdot$ ha^{-1} dry solids. The crops exhibited similar metal contents and similar responses to large amounts of metal in the sludges. Both experimental situations indicated a potential for groundwater contamination with nitrate-N when sludge application was in excess of that necessary to supply the nitrogen requirement of the growing crop. The results indicated that sludge application to land, according to the OMAF/OMOE Guidelines, would not reduce the yield or quality of the four test crops nor would it reduce groundwater quality.

KEYWORDS

Lysimeter; field; Al sludge; Fe sludge; Ca sludge; crops; toxic; metals; nitrate-N; groundwater.

INTRODUCTION

Following the 1969 International Joint Commission recommendation that phosphorus discharges from all sources in the Lower Great Lakes be reduced to the lowest practical level, Ontario treatment plants in the Lake Erie and Lake Ontario drainage basins, with capacities exceeding 4600 $m^3 \cdot d^{-1}$, were required to add chemical for phosphorus removal from wastewater. The chemicals commonly used for this purpose are aluminum sulphate, ferric chloride or waste pickle liquor, and calcium oxide or hydroxide. The sludges resulting from wastewater treatment

with these chemicals are referred to as alum (Al) sludge, iron (Fe) sludge and lime (Ca) sludge in this paper.

Numerous reports indicate that wastewater sludges exhibit fertilizer and soil conditioning properties making their disposal on farm land an attractive practice. However, at the time that phosphorus removal from wastewater was initiated in Ontario there was little information concerning land spreading of Al, Fe and Ca sludges. Consequently, field and greenhouse experiments with these sludges were initiated at the University of Guelph and lysimeter experiments were initiated at the Wastewater Technology Centre, Burlington, Ontario. The main objectives of these studies were to determine the effects of sludge application on crop yield and quality and on groundwater quality.

This paper presents and compares results obtained during 1973 to 1977 from the field and lysimeter experiments.

EXPERIMENTAL

Field Experiments - Guelph

Two experiments were conducted with corn (Zea mays L); one at Elora on Conestoga loam soil and the other at Cambridge on Caledon loamy sand soil. A third experiment was conducted on an established stand of bromegrass (Bromus inermis Leyess) at Elora on Conestoga loam soil, adjacent to the corn experiment. Selected properties of the soils are presented in Table 1.

TABLE 1 Selected Properties of the Soils (0 to 15 cm depth)

Site	Soil	pH	Organic Matter %	Sand %	Silt %	Clay %
Elora	Conestoga loam	7.3	4.9	43	44	13
Cambridge	Caledon loamy sand	7.4	2.2	74	23	3
New Liskeard	New Liskeard clay	7.2	6.4	8	59	33
Turkey Point	Plainfield sand	5.6	2.1	97	3	0

Sludges were applied to the corn experiments at rates supplying 200, 400, 800 and 1600 kg · ha^{-1} total Kjeldahl nitrogen (TKN) prior to planting in the spring. Following drying for one to two weeks, they were worked into the soil with a tandem disc. Alum sludge at 1600 kg · ha^{-1} TKN was not applied to the corn experiment on the Caledon loamy sand in 1973. Treatments with 0, 100, 200 and 400 kg · ha^{-1} N from NH_4NO_3, were included for comparison. Each treatment was applied to the same plots each year.

The same rates of sludges and NH_4NO_3 were applied to the grass experiment in three equal portions: at the beginning of growth in late April or early May, and after harvest of the first and second cuts in mid-June and in late July.

All plots on the Conestoga loam and Caledon loamy sand soils were fertilized with KCl (40 to 100 kg · ha^{-1} potassium [K]) each spring, and all plots on the Conestoga loam not receiving sludge were fertilized with superphosphate (43 to 50 kg · ha^{-1} phosphorus [P]). Phosphate fertilizer was not required on the Caledon loamy sand. Liquid fertilizer containing 40, 8 and 5 kg · ha^{-1} N, P and K, respectively, was banded with the corn seed at planting. Further details of the field experiments are available in a report by Soon and co-workers (1978).

LYSIMETER EXPERIMENTS - BURLINGTON

One experiment with orchard grass (Dactylis glomerata L) Frode variety, employed fluid sludges and a second experiment with winter wheat (Triticum aestivum) Genesee variety, and spring wheat (Triticum aestivum) Glenlea variety, employed air-dried sludges. The orchard grass experiment, initiated in 1973, was a randomized block design with three replicates of eleven fertility treatments on two soil types. The lysimeters were 30.5 cm diameter by 183 cm deep. The fertility treatments included three rates of three sludges and two controls. The soils were Caledon loamy sand Conestoga loam, the same soils on which the University of Guelph field trials were located. Alum, Fe and Ca sludges were applied at rates of 100, 200 and 300 kg · ha^{-1} TKN and NPK

fertilizer was applied to one of the control treatments at 100, 14.5 and 26.5 kg · ha^{-1} N, P and K, respectively. The second control treatment received neither sludge nor fertilizer. The sludge and fertilizer applications were made at the beginning of all but one growing season and following all but one harvest of orchard grass. The sludges and fertilizer were applied 3, 5, 5, 4 and 5 times, respectively, during 1973, 1974, 1975, 1976 and 1977. Sewage sludge contains little potassium and deficiency symptoms were observed late in the 1974 growing season. Thereafter, muriate of potash at 166 kg · ha^{-1} was applied to all sludge and the NPK control treatments at the beginning of each growing season.

The wheat experiment, initiated in 1974, was a randomized block design with two replicates of eleven fertility treatments on two soil types. The lysimeters were 61 cm square by 76 cm deep. The fertility treatments included three rates of three sludges and two controls. The soils were Plainfield sand and New Liskeard clay (Table 1). Applications of Al, Fe and Ca sludges during 1974 were related to the Chumbley (1971) "zinc equivalent" (ZE) formula based on the relative toxicities to plants of zinc, copper and nickel. The maximum recommended ZE application is 19 kg · ha^{-1} · a^{-1}. Air-dried sludges were applied on two occasions during 1974 to the surface 15 cm of soil at cumulative rates of 114, 228 and 342 kg · ha^{-1} ZE giving a maximum loading 18 times the recommended maximum annual rate. No sludge was applied during 1975 or the growing season of 1976, but then additional Al and Fe sludges were added following the final 1976 harvest so that all three sludges supplied equivalent cumulative TKN loadings. Neither control treatment received sludge but one received NPK commercial fertilizer at 60, 26 and 50 kg · ha^{-1} N, P and K, respectively, when crops were seeded. Winter wheat on the commercial fertilizer treatment received an additional 60 kg · ha^{-1} N when growth began in the spring. Muriate of potash at 50 kg · ha^{-1} K was applied to all sludge treatments in the fall of 1976. During the period 1974 to 1977, one crop of winter wheat (1975) and three crops of spring wheat were grown.

Leachates from the lysimeters were collected and analyzed to determine the effects of sludge application on groundwater quality.

SLUDGES

Attempts were made to use the same Al, Fe and Ca sludges in the lysimeter experiments as were used in the field experiments. However, due to problems with transport and timing, this was not always possible. The Fe sludge from North Toronto, the Ca sludges from Newmarket and Midland and the Al sludge from Point Edward, were the same ones used in the field. In addition, Al sludge from Tillsonburg was used in the lysimeters and Al sludges from Kitchener and Guelph were used in the field. Typical characteristics of the sludges are presented in Table 2.

Cumulative constituent loadings at the high application rates of sludge to the lysimeter and field experiments are presented in Table 3. Data for the Elora corn experiment were similar to those for Cambridge and are not shown. There was general agreement between the loadings for all experiments, however, some differences occurred. For example, the loadings of Ca sludge solids were larger than for Al or Fe sludges because the treatments supplied equal amounts of nitrogen and the nitrogen content of Ca sludge was low (Table 2). Similarly, the large nickel loadings with Ca sludge were due to application of Midland sludge and the large chromium loadings with Al sludge were due to application of Kitchener sludge (Table 2). The metal loadings in sludge generally exceeded, and in several cases considerably exceeded, the maximum recommended additions to Ontario agricultural lands (OMAF/OMOE, 1978).

TABLE 2 Typical Sludge Properties

P Removal Chemical	Source and Year	Sewage Treatment	pH	DM	Total N	P	Cd	Zn	Cu	Ni	Pb	Cr
				$mg \cdot ml^{-1}$			$\mu g \cdot ml^{-1}$					
Alum	Point Edward F and L, 1973[a]	Primary	7.2	42	1.1	1.4	0.5	75	16	1.8	10	3.8
Alum	Kitchener F, 1974-75	Secondary	7.3	54	2.7	1.9	0.4	281	30	19	24	384
Alum	Guelph F, 1976-77	Secondary	7.1	41	1.8	1.5	3.6	576	89	3.8	70	112
Alum	Tillsonburg[b] L, 1974-77	Secondary	7.6	39	1.8	1.4	3.4	403	71	5	60	88
Iron	North Toronto F and L, 1973-77	Secondary	7.3	70	2.9	3.3	1.4	145	114	1.6	115	46
Lime	Newmarket[c] F, 1973-75	Secondary	7.0	84	1.2	0.8	0.2	78	21	2.2	16	2.6
Lime	Midland F, 1976-77	Primary	6.9	65	1.1	3.2	0.6	240	48	268	43	163

a Sludge applied to the field (F) and lysimeter (L) experiments during 1973 to 1977.
b The cadmium content of Tillsonburg sludge prior to 1976 was 0.3 $\mu g \cdot ml^{-1}$.
c Newmarket sludge was applied to the lysimeter experiment growing wheat during 1974 to 1977. It was also applied to the lysimeter experiment growing orchard grass during 1973 to 1975 but then Midland sludge was applied during 1976 to 1977.

RESULTS

Crop Yield

Except for 1977, the annual yields of orchard grass grown on Conestoga loam soil were much larger than the annual yields of bromegrass (Fig. 1). These differences in yield probably reflected differences in growth between the grass species in addition to irrigation, a longer growing season and large border effects with the lysimeters at Burlington.

Orchard grass yields increased with increasing sludge application rate throughout 1973 to 1977 and increased with time from 1973 to 1975. Reduced yields during 1976 and 1977 were attributed to soil infestation with June bug larvae which reduced plant population and growth. Except for the Al sludge treatment in 1973, yields from the high application rates of sludge exceeded the yield from commercial fertilizer and exceeded the mean yield for all sludge and fertilizer treatments. Alum sludge from Point Edward which contained a large amount of petroleum hydrocarbon (Chawla, Stephenson and Liu, 1974) reduced yields of both the orchard grass and bromegrass in 1973. Following 1973, Al sludge from Tillsonburg was applied to the orchard grass and from Kitchener was applied to the bromegrass and exhibited no detrimental effects on yields. Orchard grass yields from Caledon loamy sand soil were somewhat smaller than from Conestoga loam soil, but exhibited similar trends.

TABLE 3 Constituent Loadings ($kg \cdot ha^{-1}$) at the High Application Rates of Sludge

Constituent	Alum	Iron	Lime	Alum	Iron	Lime	Maximum Recommended Metal Additions to Ontario Agricultural Lands*
	Lysimeter - Orchard Grass, 1973 - 1977			Field - Bromegrass, 1973 - 1977			
N	6 600	6 600	6 600	8 000	8 000	8 000	-
P	5 603	3 821	6 106	6 480	7 760	9 920	-
Zn	653	459	670	944	440	672	363
Cu	179	246	200	224	248	168	168
Ni	14.3	6.1	910	34	5.5	624	36
Cd	6.2	4.3	2.8	7.2	3.6	2.5	1.6
Cr	144	104	320	688	85	328	220
Pb	122	278	118	153	296	126	94
Sludge solids ($tonnes \cdot ha^{-1}$)	156	158	390	186	172	471	-
	Lysimeter - Wheat, 1974 - 1977			Field - Corn (Cambridge), 1973-1977			
N	6 984	6 984	6 984	8 000	8 000	8 000	-
P	14 178	12 775	7 912	6 440	7 744	9 440	-
Zn	341	579	164	1 032	520	784	363
Cu	219	320	73	240	240	176	168
Ni	6.3	5.2	3.5	36	8.8	536	36
Cd	4.0	7.4	1.5	7.4	3.4	2.6	1.6
Cr	52	138	14.0	736	144	336	220
Pb	133	450	46	168	288	152	94
Sludge solids ($tonnes \cdot ha^{-1}$)	298	276	426	194	167	499	-

* Source: OMAF/OMOE (1978) Guidelines for Sludge Utilization on Agricultural Lands.

Bromegrass yields exhibited an increasing trend from 1973 to 1977. In general, yields from the high application rate of sludges equalled or exceeded the yield from 400 kg · ha^{-1} NH_4NO_3 and the mean yield for all sludge and fertilizer treatments. A detailed discussion of bromegrass yields during 1973 to 1975 is presented by Soon and co-workers (1978). During that time, yield was increased by NH_4NO_3 at rates up to 400 kg · ha^{-1} N and by all sludges at rates up to 800 kg · ha^{-1} TKN. Subsequently, yield was increased by NH_4NO_3 at rates up to 200 kg · ha^{-1} N and by all sludges at rates up to 400 kg · ha^{-1} TKN. These results indicated a substantial residue value to bromegrass of N in both NH_4NO_3 and sludge and no detrimental effect of heavier sludge applications than were necessary to produce maximum yields.

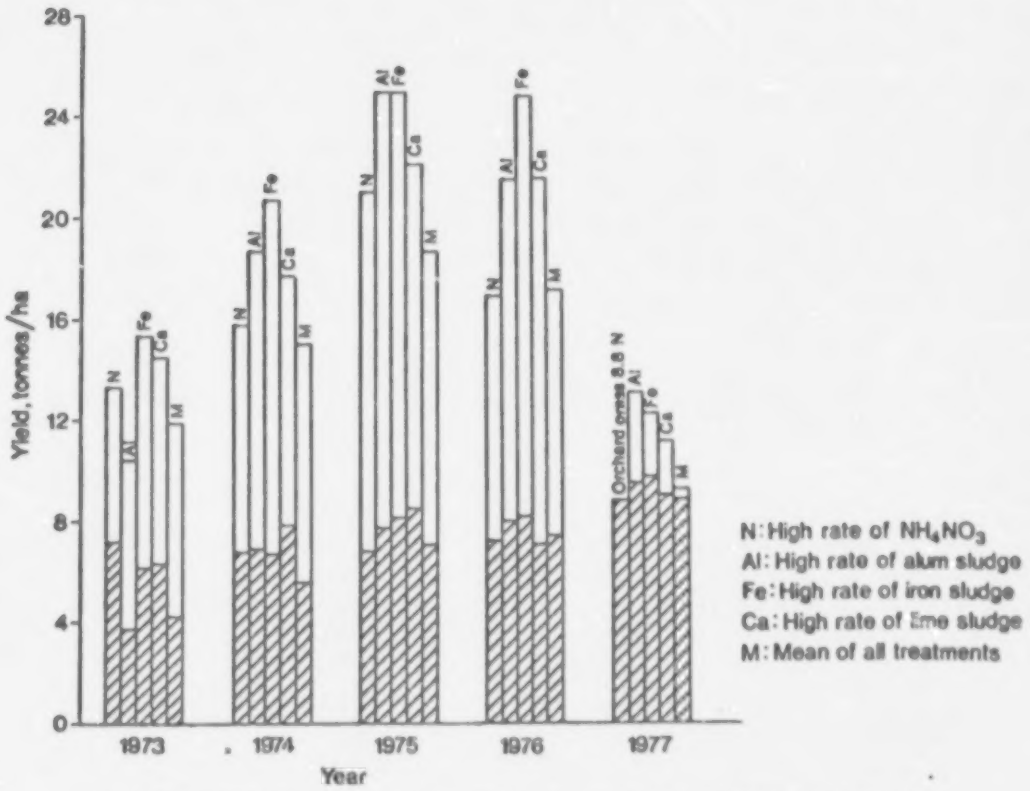

Fig. 1. Annual yields of orchard grass (total bar) and bromegrass (hatched bar) grown on Conestoga loam soil treated with commercial fertilizer and sewage sludge

Wheat grain and straw yields from Plainfield sand exhibited wide variations from year to year (Fig. 2a). Winter wheat grown during 1975 produced much larger yields than spring wheat grown during 1974, 1976 and 1977. The very low yields from sludge treatments during 1976 were due to potassium deficiency which was subsequently rectified by adding muriate of potash. There were no consistent differences in yields between the treatments. Yields from the New Liskeard clay soil were somewhat larger than from the sand and potassium deficiency was not observed, but otherwise treatment effects on the two soils were similar.

Corn grain and stover yields from Caledon loamy sand were reduced by drought during 1973 to 1975, but not appreciably during 1976 and 1977 (Fig. 2b). The yields were increased by NH_4NO_3 at rates up to 100 kg · ha^{-1} N and by sludge rates up to 200 kg · ha^{-1} TKN. There were no consistent differences in yields between Al, Fe and Ca sludge treatments supplying equivalent TKN loadings. Yields from the Conestoga loam soil were less affected by drought and were larger than from the Caledon loamy sand soil. Otherwise, the data from the two experiments were similar. A detailed discussion of the corn yield data during 1973 to 1975 is presented by Soon and co-workers (1978).

CROP QUALITY - NITRATE

Nitrate-N concentrations larger than 3 mg · g^{-1} in forage may be hazardous to livestock. Nitrate-N concentrations in orchard grass were not monitored on a regular basis, however, some data were available for 1978. Concentrations increased with increasing sludge application rate, but did not exceed 2 mg · g^{-1}. Similarly, concentrations in bromegrass and corn stover increased with increasing rates of NH_4NO_3 and sludges, but exceeded the 3 mg · g^{-1} limit only on Caledon loamy sand during 1975 (Soon and co-workers, 1978). No data were available for wheat straw.

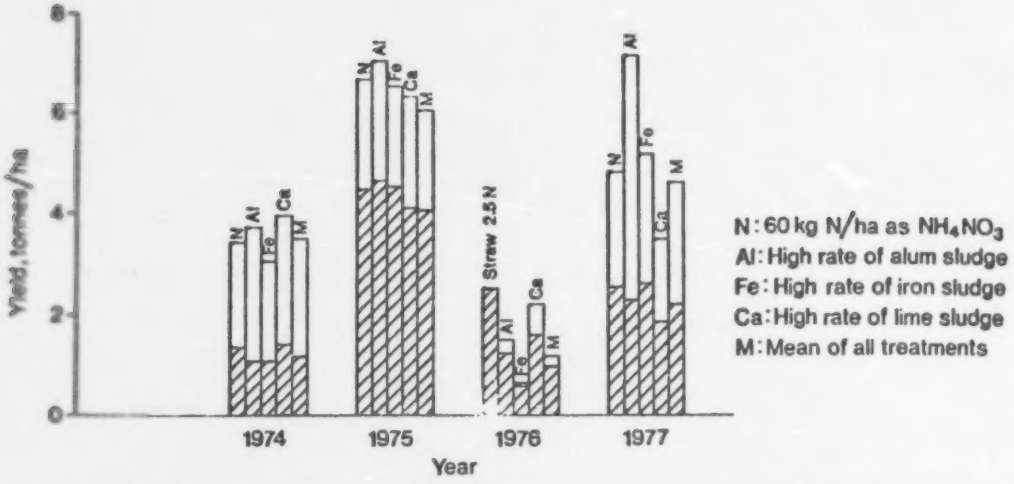

Fig. 2 a. Annual yields of wheat straw (total bar) and grain (hatched bar) grown on Plainfield sand soil treated with commercial fertilizer and sewage sludge

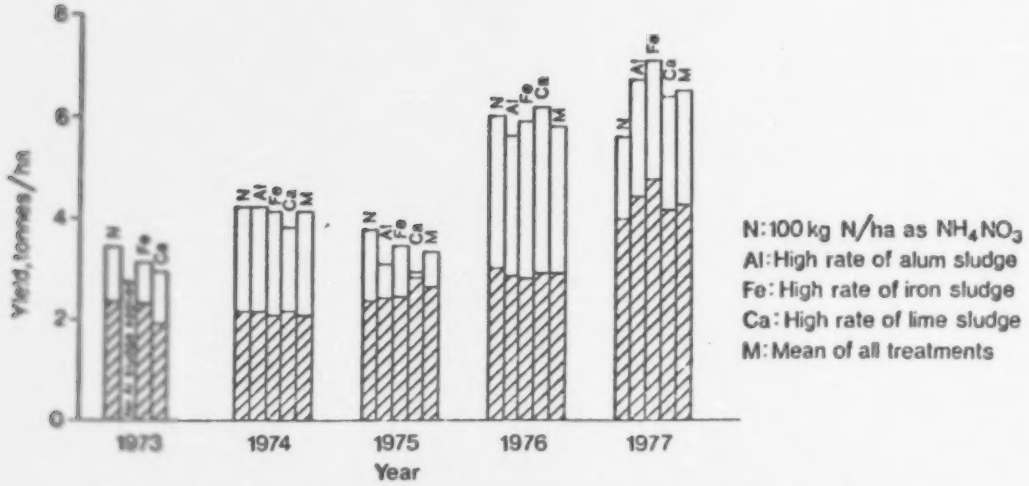

Fig. 2 b. Annual yields of corn grain (total bar) and stover (hatched bar) grown on Caledon loamy sand soil treated with commercial fertilizer and sewage sludge

CROP QUALITY - METALS

In general, the Al sludge treatments supplied the largest loadings of cadmium and zinc to the experimental soils (Table 3). Similarly, the Fe sludge treatments supplied the largest loadings of copper, and the Ca sludge treatments supplied the largest loadings of nickel. A comparison of metal concentrations in crops grown on these and the commercial fertilizer treatments is contained in Fig. 3. Data are presented for the high rates of sludge application and for NH_4NO_3 applied to bromegrass at 400 kg · ha^{-1} N and to corn at 100 kg · ha^{-1} N. Values are presented for orchard grass and bromegrass grown on Conestoga loam soil, wheat grown on Plainfield sand and corn grown on Caledon loamy sand. Values were not available for all harvests of bromegrass and those presented are for the first harvest each year, which averaged 60% of the annual yield.

Metal concentrations in orchard grass grown on Caledon loamy sand soil, wheat grown on New Liskeard clay and corn grown on Conestoga loam are not shown in Fig. 3. They were similar to or lower than the values shown.

Cadmium. Cadmium loadings through 1977 with the high rates of Al sludge applied to the lysimeter and field experiments considerably exceeded the maximum recommended addition to Ontario agricultural lands (Table 3). Moreover, loadings during 1976 and 1977 to the orchard grass, bromegrass and corn experiments were much larger than in previous years due to an increase in the cadmium content of Tillsonburg sludge and application of Guelph sludge (Table 2). Cadmium levels for crops grown on the sludge treatments were generally, but not always, larger than on the commercial fertilizer treatments (Fig. 3). The data for both treatments exhibited a considerable year-to-year variation. Corn stover exhibited the highest background levels of cadmium and was the only material to show a very marked effect of sludge treatment. The cadmium content of corn stover increased from about 0.5 to 1.0 $\mu g \cdot g^{-1}$ with the application of Guelph sludge. Much smaller increases in the cadmium contents of

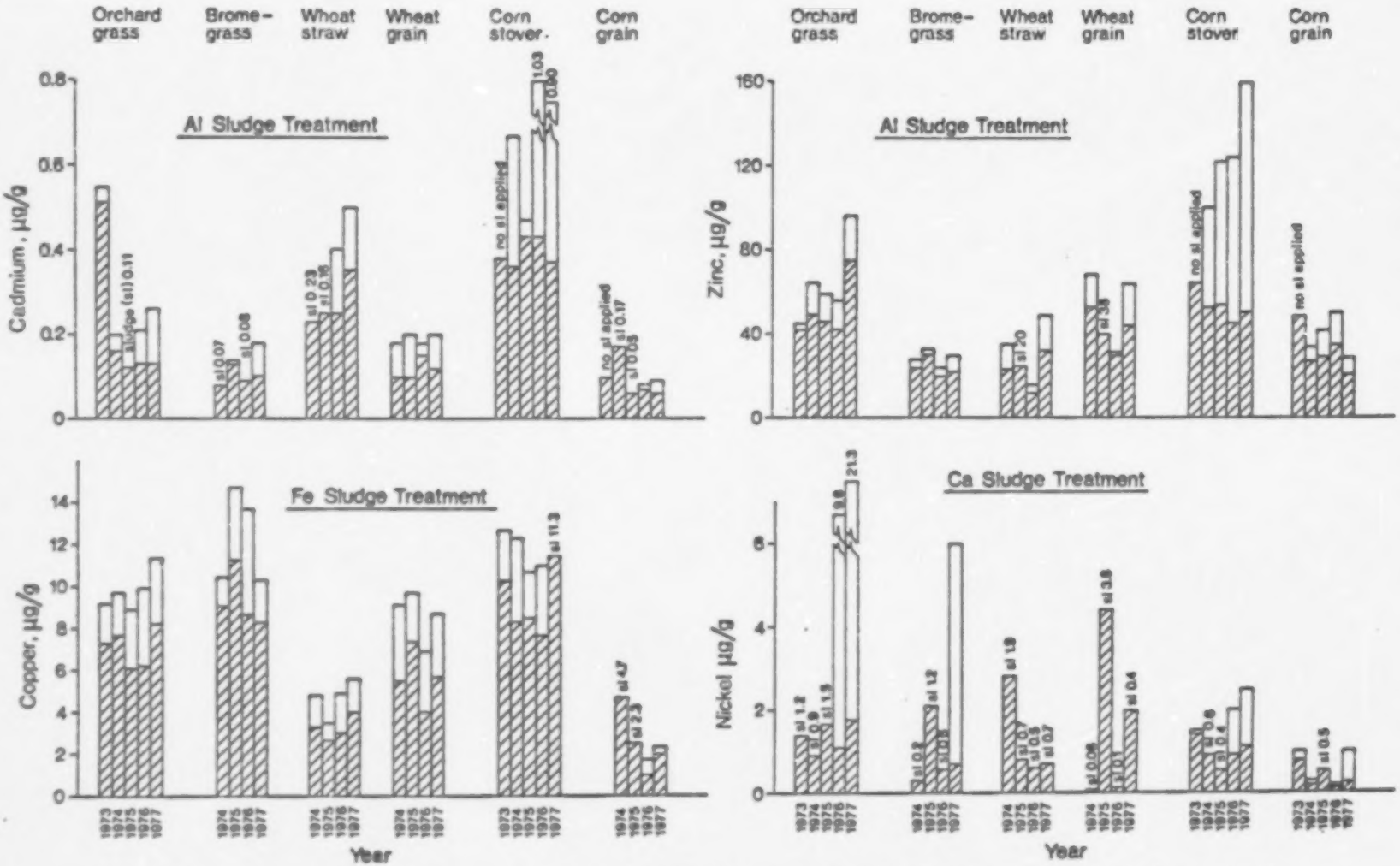

Fig.3. Metal concentrations (µg/g) in crops grown on soils treated with sludge (total bar) and commercial fertilizer (hatched bar)

1976 and 1977 orchard grass and 1977 bromegrass also possibly were due to sludge application. No increase was observed for the 1976 bromegrass because Guelph sludge was not applied prior to the first harvest. Whereas wheat grain grown with sludge exhibited consistently higher cadmium levels than that grown with commercial fertilizer, corn grain exhibited no consistent effect of sludge. Wheat grain contained less cadmium than wheat straw and corn grain contained much less cadmium than corn stover. The high levels of cadmium reported for 1973 orchard grass may reflect analytical error.

Zinc. Up to 1977, the high application rates of Al sludge supplied approximately three times the recommended maximum loading of zinc to the soils growing bromegrass and corn, approximately two times the maximum loading to the soil growing orchard grass and approximately the maximum loading to the soil growing wheat (Table 3). Sludge application caused small increases in the zinc content of bromegrass, small to moderate increases in the zinc content of orchard grass, wheat straw and the grains, and it more than doubled the zinc content of corn stover (Fig. 3). With the exception of corn stover which exhibited increasing zinc content with increasing sludge application, the differences between data for the sludge and commercial fertilizer treatments remained approximately constant with time. Wheat grain contained more zinc than wheat straw, and corn grain contained less zinc than corn stover.

Copper. Up to 1977, the high application rates of Fe sludge supplied approximately one and one-half times the recommended maximum loading of copper to the experimental soils (Table 3). Sludge application moderately increased the copper content of the crops, but the differences between data for the sludge and commercial fertilizer treatments did not increase with time (Fig. 3). Wheat grain contained more copper than wheat straw and corn grain contained much less copper than corn stover.

Nickel. The data for bromegrass, wheat straw and grain, and corn grain grown on the commercial fertilizer treatment exhibited a considerable year-to-year variation and indicated that both the Burlington and Guelph laboratories experienced difficulty analyzing low concentrations of nickel in plant materials. However, despite uncertainty in the data, the following comments are presented.

The nickel loadings in Ca sludge applied to the soils growing orchard grass, bromegrass and corn were far in excess of the maximum recommended addition (Table 3). Wheat received Newmarket sludge containing little nickel (Table 2) and exhibited no increase in nickel content over that for the commercial fertilizer treatment (Fig. 3). Similarly, orchard grass, bromegrass and corn received Newmarket sludge during 1973 to 1975 and exhibited no increase in nickel content over that for the commercial fertilizer treatment. Then, in 1976, Midland sludge containing a large amount of nickel was applied. Large increases in the nickel content of sludge treated orchard grass were observed in 1976 and 1977 and in bromegrass in 1977. No increase was observed for the 1976 bromegrass because Midland sludge was not applied prior to the first harvest. Moderate increases in the nickel content of corn stover were observed in 1976 and 1977 and in corn grain in 1977.

Lead and Chromium. The data were variable indicating that both the Burlington and Guelph laboratories experienced difficulty analyzing low levels of lead and chromium in plant materials. However, the following comments are presented.

In general, the Fe and Al sludges contributed the largest loadings of lead and chromium, respectively, to the experimental soils. Several of the loadings with these sludges greatly exceeded the maximum recommended additions to Ontario agricultural lands (Table 3). However, there was no difference in lead content and, with the exception of corn stover, no difference in chromium content between crops grown with and without sludge. The chromium content of corn stover grown with commercial fertilizer was about 2 $\mu g \cdot g^{-1}$ and with Al sludge about 4 $\mu g \cdot g^{-1}$. The Fe and Ca sludges did not increase the chromium content of corn stover. Chromium levels in the grasses and wheat straw were about 1.5 $\mu g \cdot g^{-1}$ and in the grains less than 1 $\mu g \cdot g^{-1}$. The lysimeter site is near a major highway and lead levels in the orchard grass and wheat straw averaged 8 $\mu g \cdot g^{-1}$, probably due to contamination from automobile exhaust. Levels in the bromegrass and corn stover averaged 2 and 8 $\mu g \cdot g^{-1}$, respectively. Wheat and corn grain averaged 0.5 $\mu g \cdot g^{-1}$.

NUTRIENT AND METAL LEACHING

Analysis of leachates from the lysimeter experiments indicated nitrate-N movement through soils which received sludge at rates in excess of that necessary to supply the nitrogen requirement of the growing crop. Levels exceeding 100 $\mu g \cdot ml^{-1}$ nitrate-N were observed. Similarly, Soon and co-workers (1978) observed nitrate-N buildup in the soil profile during the 1975 growing season where high rates of sludge had been applied in the field. Measurements the following April indicated that the buildup had disappeared, possibly by leaching and denitrification.

Soils in both the lysimeter and field experiments received very heavy loadings of phosphorus in sludge (Table 3). However, analysis of leachates from the lysimeters indicated that there was little, if any, movement of phosphorus with groundwater. Phosphorus levels in the leachates showed no increasing trend with time and, with few exceptions, were less than 1 $\mu g \cdot ml^{-1}$. Plant-available phosphorus in the field soils increased with increasing sludge application (Soon, Bates and Moyer, 1978).

The metal levels in leachates from the lysimeter experiments did not increase with time and were less than the maximum permissible levels defined for drinking water in Canada (NH&W, 1969).

DISCUSSION

The lysimeter experiments at Burlington and the field experiments at Guelph were similar in many respects. Their main objectives were to determine the effects of Al, Fe and Ca sludges on crop yield and quality and on groundwater quality. Repeated heavy applications of Al, Fe and Ca sludges were applied to soils and crops were grown. Two soils, the Conestoga loam and Caledon loam sand, were common to both experimental situations. No crops were common, however, all were field crops grown in southern Ontario.

Similar results were obtained from the lysimeter and field experiments. Crop yields with sewage sludge were as large as, or larger than, those with commercial fertilizer and there were no consistent differences between yields from the Al, Fe and Ca sludge treatments. There was no evidence of yield reduction even from the highest rates of sludge application which ranged up to 499 tonnes · ha^{-1} dry solids. The crops exhibited similar metal contents and similar responses to large amounts of metal in sludge. Both experimental situations indicated a potential for groundwater contamination with nitrate-N when sludge application was in excess of that necessary to supply the nitrogen requirement of the growing crop.

Similarly, De Vries and Tiller (1978) reported that the metal contents of lettuce tops and onion bulbs grown outside on sludge treated soils in 1 m x 1 m mini plots were in line with those grown on sludge treated soils in the field. The same crops grown with the same soil and sludge treatments in the greenhouse exhibited much higher metal contents. Thus, it appears that metal uptake resulting from land application of sludge may be studied with lysimeter or mini plot experiments as effectively as with the more expensive field plot experiments. The lysimeters at Burlington were much like the mini plots employed by De Vries and Tiller (1978). They were approximately the same size, were located outside, were drained to prevent buildup of a water table, and were irrigated with distilled water when rainfall was inadequate for optimum crop growth.

The high rates of sludge application to the lysimeter and field experiments generally caused small to moderate increases in the metal contents of the crops. Large increases in the cadmium and zinc contents of corn stover and in the nickel contents of grasses reflected the application of sludges containing unusually large amounts of these metals. These observations were in general agreement with findings by Dowdy and Larson (1975) who applied up to 450 tonnes · ha^{-1} of a relatively low metal content sludge and reported small to moderate increases in the metal contents of vegetable crops except for lettuce.

Sludge was applied one or more times annually to the lysimeter and field experiments so that the metal loadings to soils increased with time. However, with the exception of nickel in orchard grass and zinc and possibly cadmium in corn stover, there was no evidence of increasing metal content in the crops with repeated sludge application.

The relative importance of single versus repeated applications of sewage sludge on the metal contents of crops is currently a question of considerable concern because it bears significant implications for the economics of sludge application on land. To date this question has not been satisfactorily resolved, however, a majority of reports attribute greater importance to applications immediately prior to, or during, growth of the crop than to total amounts applied in previous years. For example, Bates and co-workers (1975) reported increased metal concentrations in ryegrass with a single sludge application but no further increase with repeated applications from one crop to the next at any of the rates applied. Similarly, Hinesly and co-workers (1977) reported that the main factors controlling assimilation of zinc and cadmium by corn were the amounts applied immediately prior to planting. However, Giordano, Mortvedt and Mays (1975) reported that zinc concentrations in corn forage from half-plots that continued to receive sludge application in the second year was appreciably higher than from half-plots that received sludge the previous year only. No increases were reported for cadmium, nickel and lead.

Corn grain exhibited lower metal contents than corn stover as reported by various authors (Webber, 1978), however, wheat grain contained less cadmium and nickel, but more zinc and copper than wheat straw. Zinc cadmium and nickel accumulation in wheat grain has been reported by Mitchell, Bingham and Page (1978) and nickel accumulation in sweet corn grain and bush bean pods by Giordano, Mortvedt and Mays (1975). Zinc and copper accumulation in snapbean edible tissue following heavy applications of sludge has been reported by Dowdy and co-workers (1978). Thus, metals appear to be largely excluded from the grain of corn but evidence is mounting that this is not the case for all crops.

In many cases, metal loadings to the lysimeter and field experiment soils greatly exceeded the recommended maximum additions to Ontario agricultural lands (Table 3). However, with the exception of nickel in the 1976 and 1977 grasses and cadmium in corn stover, metal levels in the crops fell within normal background ranges as suggested by Blakeslee (1976). The high application rate of Midland sludge added more than 17 times the recommended maximum addition of nickel to the soils growing grass. The high application rate of A1 sludge more nearly approximated the recommended addition, and the nickel contents of 1977 orchard grass and bromegrass grown with that sludge were 1.4 and 1.7 $\mu g \cdot g^{-1}$, respectively. These levels compare with 1.7 and 0.7 $\mu g \cdot g^{-1}$ for the commercial fertilizer treatment. Similarly, the high application rate of A1 sludge added more than four times the recommended maximum addition of cadmium to the soil growing corn. The high application rate of Ca sludge more nearly approximated the recommended maximum addition, and the cadmium content of 1977 corn stover grown with that sludge was 0.44 $\mu g \cdot g^{-1}$. This compared with a value of 0.37 $\mu g \cdot g^{-1}$ for the commercial fertilizer treatment. The pH values in 1977 of the soil growing corn were: A1 sludge treatment, 7,3; Ca sludge treatment, 7.9; and commercial fertilizer treatment, 7.4.

The results of the lysimeter and field experiments indicated that sludge application to land, according to the OMAF/OMOE (1978) Guidelines, would not reduce the yield or quality of the four field crops grown. Large increases in the metal contents of the crops and in nitrate-N content of groundwater occurred only where sludge applications greatly exceeded the amounts recommended. Moreover, it appeared that the Guidelines allow an appreciable margin for error which is considered desirable because sludge composition can vary widely over time (Monteith and Stephenson, 1978).

It is well established that crops differ with respect to metal uptake and that some vegetable crops accumulate much more metal than the field crops used in these experiments. Since land that is currently under field crop production might, at sometime in the future be used for vegetable production, it is essential that experiments with vegetable crops be done to test the Guidelines. An experiment with swiss chard is currently in progress at Burlington and experiments with other green leafy vegetables are planned.

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THE FUTURE OF SLUDGE REGULATION IN BRITISH COLUMBIA

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THE FUTURE OF SLUDGE REGULATION IN BRITISH COLUMBIA

1.0 INTRODUCTION

The Pollution Control Act came into being in 1967 and charged that after the first day in January 1970 no person was allowed to discharge sewage or other waste material on, in or under any land or into any water without a permit or approval from the Director of Pollution Control. The staffing required to administer this Act was essentially complete in 1970 and since then control over effluent discharges, air discharges and refuse discharges have been established by a system of Permits. Controls of storm overflows, storm water and street runoff and the final disposal of sludge have not yet been established. In the past much public concern has been expressed over discharges of effluent, air and refuse and the Pollution Control Branch has responded to those concerns. Little public concern has been expressed regarding the final disposal of sludge; nor did the Pollution Control Branch have any information that the disposal of sludge had caused any serious environmental problems. At any rate it was not considered priority need be given to the question of where and how sludge should ultimately be disposed. This was reflected in a Public Inquiry held in 1973 regarding how to control pollution from Municipal Wastes and those making submissions hardly made reference to the subject of sludge disposal or the possibility of pollution from this source. The Pollution Control Objectives for Municipal Type Waste Discharges in British Columbia which resulted from this Inquiry include brief references to semi-solid wastes (Sections 3.7 and 6). Apart from stating that sludges should not be discharged to treatment plants unless they are designed to receive them disposal is only referred to as it relates to landfills, and the objectives state: "Non-digested organic sludges such as those arising from domestic sewage treatment plants or holding tanks shall not be placed on landfills. Septic tank pumpings will generally be considered to be sufficiently digested for landfill disposal." Additionally, Section 5.13 concerning treatment plants, states, "Neither sludge nor excess solids are to be discharged down outfalls except in the case of marine outfalls specifically designed for the purpose."

In British Columbia the policy is that every application is assessed on its merits and the objectives act as a guide which site-specific factors may override. However, it is obvious that the majority of the sludge in the Province must ultimately be disposed of on land.

Sludge disposal practices in the Province are coming under closer scrutiny as the treatment plants become larger and more complex with increased industrial discharges and high effluent quality standards resulting in larger quantities and kinds of sludges produced. In particular, the Greater Vancouver Sewerage and Drainage District, being the Authority responsible for sewerage for half the Provinces population, have been notified that effective source controls prior to discharge to sewers must be implemented. We may anticipate that a Public Inquiry held in January will finalize the steps necessary to this end. Whatever these may be, it seems evident that the sludge problem is going to grow and now warrants our attention.

A recent study undertaken by the Resource Recovery Section showed that present sludge disposal practices vary throughout the province but in general only well digested sludges are disposed to land. Of the communities surveyed, 40% used sludge in an agricultural manner, 35% landfilled sludge, 5% incinerated, 8% stored in sludge lagoons and 12% discharged sludge to the outfall. Digested sludge which has been dried in sludge drying beds is commonly available to farmers, parks departments and general public for use as an organic soil conditioner. Three composting operations are now in existence in the Province. All use a modification of the Indore Process combining sludge (raw, septic tank and digested) with wood waste (hog fuel or sawdust). The septic tank sludge and hog fuel compost operation is run by the Regional District of Central Okanagan and the compost product is sold to the general public. The City of Kelowna have recently begun a raw sludge-hog fuel composting operation at their landfill and plan to reclaim the landfill site with the compost product. Anaerobically digested sludge at the Iona Island treatment plant site serving Vancouver is composted with sawdust. This compost was initially sold in supermarkets but this has been suspended pending resolution of concerns about possible toxicants.

One other aspect which has caused uncertainty in the past is whether sludge is a waste. We can all perhaps agree that it is when it comes out of a primary settlement tank and perhaps most of us would agree that it still is when it comes out of a digestion tank, but whether it is when it is removed from sludge drying beds is arguable and the proper mechanism to control disposal under the Pollution Control Act is not obvious.

2.0 POLICY FOR BRITISH COLUMBIA

Having explained in brief why sludge disposal has not been controlled in British Columbia the questions remain as to whether it needs to be and if so by whom and how. We believe that those in different disciplines and different organizations who are involved in this matter should be given an opportunity to participate in the discussions that are going to be necessary before we can derive the answers. As a first step, we have written a report summarizing guidelines published elsewhere in the U.S.A., Great Britain and Canada for limited distribution. The purpose of the publication is to solicit input in formulating suitable policy for British Columbia. We hope that it will also be a useful reference document for those having to make decisions about sludge disposal at this time. We have asked recipients of this report to examine practices in this matter and to give us their views by August of this year.

3.0 REPORT ON GUIDELINES PUBLISHED ELSEWHERE

In general, most of the guidelines surveyed showed that:

- Nitrogen application is based on the needs of the crop grown. Most discrepancies between guidelines appear to be a result of different methods used to calculate the available nitrogen in the sludge.

- Phosphorus loading criteria was normally considered to be met if the nitrogen loading criteria was not exceeded. Exceptions were in the case of sandy soils where leaching of phosphorus might occur.

- Maximum total sludge loading per area of land was specified in most guidelines and related to the total amount of heavy metals added. In some guidelines this loading was the only criteria used to limit heavy metal application while others had maximum limits specified under individual metals. Most guidelines related maximum sludge loading to cation exchange capacity and pH of the soil. Several guidelines took end use of the land into account and established different maximum sludge loading rates depending on such things as zoning, whether the land was being reclaimed, used for grazing or forage production as opposed to vegetable cropping etc.

- Cadmium allowable application rates are much less straight forward than nitrogen and phosphorus. Some guidelines state a maximum application rate per year and an accumulative total which may or may not vary according to the sludge zinc to cadmium ratio. Other guidelines may limit the cadmium concentration in the sludge while still others vary the application rate according to the cation exchange capacity and pH of the soil. A further limitation may be applied regarding the type crop grown. The guidelines vary considerably in the maximum allowable application rates both annually and total:

  Maximum yearly application - 0.3 kg/Ha to 2.3 kg/Ha/yr
  Maximum total application - 1.6 kg/Ha to 22.5 kg/Ha

- Nickel, zinc, copper and lead application rates in most guidelines were related to maximum allowable weight (lbs, kg) per area (acre, hectares) depending on the cation exchange capacity and pH of the soil.

  Allowable maximum values vary:

Nickel	13 kg/Ha to 200 kg/Ha
Zinc	134 kg/Ha to 1000 kg/Ha
Copper	67 kg/Ha to 500 kg/Ha
Lead	67 kg/Ha to 2000 kg/Ha

- As opposed to defining quantities of different materials which could be applied per unit of area some guidelines controlled the rate of application by stating maximum metal concentrations in the sludge.

Cadmium	10 mg/kg to 25 mg/kg
Nickel	200 mg/kg to 2500 mg/kg
Copper	1000 mg/kg
Lead	700 mg/kg to 1000 mg/kg

- Mercury and chromium were mentioned in fewer guidelines than were the previously listed metals. Maximum concentrations in the sludge were stated criteria in some guidelines while others had accumulated total load in some cases related to a soil pH of 6.5.

Maximum concentration in sludge

Mercury	10 mg/kg
Chromium	1000 mg/kg

Accumulated total load

Mercury	0.2 kg/Ha to 2 kg/Ha
Chromium	67 kg/Ha to 1000 kg/Ha

- Selenium, molybdenum, boron, arsenic and cobalt are present in only a few guidelines.

Accumulative total permissible is:

Selenium	2.7 kg/Ha to 5 kg/Ha
Molybdenum	2.7 kg/Ha to 5 kg/Ha
Cobalt	30 kg/Ha
Arsenic	10 kg/Ha to 15 kg/Ha

A yearly total for Boron depends on whether the land is pasture or arable.

Pasture	5 kg/Ha/yr to 7 kg/Ha/yr
Arable	3.5 kg/Ha/yr to 5 kg/Ha/yr

- Monitoring of the sludge on a regular basis was required in most guidelines while soil and crop monitoring programs were site specific.

- The time period required prior to the use of the land varied considerably among the guidelines:

  (1) Horses and cattle grazing varied from - physical contamination to be removed by rain - 2 weeks - 45 days - 2 months - 6 months

  (2) Sheep and swine grazing varied from - physical contamination removed by rain - 45 days - 6 months

  (3) Fruit and vegetables varied from 6 months to 1 year to 3 years.

4.0 EPA LAND DISPOSAL CRITERIA

In October of last year the U. S. Environmental Protection Agency issued final criteria setting minimum standards for the land disposal of non-hazardous wastes under the Resource Conservation and Recovery Act. This included landspreading of municipal sewage treatment sludge.

In general, there were restrictions on siting of facilities in flood plains and where endangered species of plants, fish or wildlife were present. Specific sludge disposal practices included:

(a) Sludge disposal practice was not to cause the discharge of pollutants into surface waters.

(b) The facility or practice was not allowed to contaminate an underground drinking water source beyond the facility boundary or beyond an alternative boundary which may be specified by the State under certain conditions. An underground drinking water source was described as an aquifer supplying drinking water for consumption or one in which the groundwater contained less than 10,000 mg/L total dissolved solids. Contaminate means to introduce a substance that would cause the concentration of that substance in the groundwater to exceed the maximum contaminant level specified. Contaminant levels were specified for inorganic chemicals (arsenic, barium, cadmium, chromium, lead, mercury, nitrate, selenium, silver, flouride), organic chemicals (endrin, lindane, methoxychlor, toxaphene, 2-4-D, 2-4-5-TP silvex); and coliform bacteria.

(c) The application of sludge to land used for the production of food-chain crops was allowed provided:

(1) the pH of the soil-sludge mixture is 6.5 or greater (except for sludges containing less than 2 ppm cadmium)

(2) the annual application of cadmium does not exceed 0.5 kg/hectare on land used for production of tobacco, leafy vegetables or root crops grown for human consumption. For other food chain crops the allowable annual cadmium application rate varies from 2.0 kg/Ha to 0.5 kg/Ha on a time basis between now and 1987.

i.e. - Present to June, 1984 - 2.0 kg/Ha
June, 1984 to Dec., 1986 - 1.25 kg/Ha
Beginning January, 1987 - 0.5 kg/Ha

(3) the cumulative application of cadmium does not exceed

Soil cation exchange capacity (meq/100 g)	Maximum cummulative application (kg/Ha) Background soil pH <6.5	Background soil pH ≥6.5
>5	5	5
5 - 15	5	10
<15	5	20

(4) Where the only food chain crop produced is animal feed the cadmium restrictions noted in (2) and (3) above are eliminated provided:

(i) there is a facility operating plan which demonstrates how the animal feed will be distributed to preclude ingestion by humans and describes the measures to be taken to safeguard against possible health hazards from cadmium entering the the food-chain which may result from alternative land uses.

(ii) future property owners are notified by a stipulation in the land record or property deed which states that the property has received solid waste at high cadmium application rates and that food-crops should not be grown due to possible health hazards.

(5) sludge containing concentrations of polychlorinated biphenyls (PCB's) equal to or greater than 10 mg/kg (dry weight) must be incorporated into the soil when applied to land used for producing animal feed. This is not required if it is assured that the PCB content is less than 0.2 mg/kg (actual weight) in animal feed or less than 1.5 mg/kg (fat basis) in milk.

(d) In regard to the control of disease when sewage sludge disposal to land is practiced the following criteria were outlined:

(1) Sewage sludge that is applied to the land surface or incorporated into the soil is to be treated by a "Process to Significantly Reduce Pathogens" prior to application or incorporation. Processes to significantly reduce pathogens are described as:

AEROBIC DIGESTION: The process is conducted by agitating sludge with air or oxygen to maintain aerobic conditions at residence times ranging from 60 days at 15°to 40 days at 20°C, with a volatile solids reduction of at least 38%.

AIR DRYING: Liquid sludge is allowed to drain and/or dry on under-drained sand beds, or paved or unpaved basins in which the sludge is at a depth of nine inches. A minimum of three months is needed, two months of which temperatures average on a daily basin above 0°C.

ANAEROBIC DIGESTION: The process is conducted in the absence of air at residence times ranging from 60 days at 20°C to 15 days at 35°C to 55°C, with a volatile solids reduction of at least 38%.

COMPOSTING: Using the within-vessel, static aerated pile or windrow composting methods, the solid waste is maintained at minimum operating conditions 40°C for 5 days. For four hours during this period the temperature exceeds 55°C.

LIME STABILIZATION: Sufficient lime is added to produce a pH of 12 after two hours of contact.

OTHER METHODS: Other methods or operating conditions may be acceptable if pathogens and vector attractions of waste (volatile solids) are reduced to an extent equivalent to the reduction achieved by any of the above methods.

Public access to the facility must be controlled for at least 12 months and grazing by animals whose products are consumed by humans must be prevented for at least one month. Crops for direct human consumption must not be grown within 18 months of application or incorporation (this only applies to crops where the edible portion can come in contact with sludge).

If such crops for direct human consumption are to be grown within 18 months subsequent to application or incorporation then the sludge must be treated by a "Process to Further Reduce Pathogens" prior to application. "Processes to Further Reduce Pathogens are described as:

COMPOSTING: Using the within-vessel composting method, the solid waste is maintained at operating conditions of 55°C or greater for three days. Using the static aerated pile composting method, the solid waste is maintained at operating conditions of 55°C or greater for three days.

Using the windrow composting method, the solid waste attains a temperature of 55°C or greater for at least 15 days during the composting period. Also, during the high temperature period, there will be a minimum of five turnings of the windrow.

HEAT DRYING: Dewatered sludge cake is dried by direct or indirect contact with hot gases, and moisture content is reduced to 10% or lower. Sludge particles reach temperatures well in excess of 80°C, or the wet bulb temperature of the gas stream in contact with the sludge at the point where it leaves the the dryer is in excess of 80°C.

HEAT TREATMENT: Liquid sludge is heated to temperatures of 180°C for 30 minutes.

THERMOPHILIC AEROBIC DIGESTION: Liquid sludge is agitated with air or oxygen to maintain aerobic conditions at residence times of 10 days at 55 - 60°C, with a volatile solids reduction of at least 38%.

OTHER METHODS: Other methods or operating conditions may be acceptable pathogens and vector attraction of the waste (volatile solids) are reduced to an extent equivalent to the reduction achieved by any of the above methods.

Any of the processes listed below, if added to the processes to significantly reduce pathogens will further reduce pathogens. Because these processes do not reduce the attraction of disease vectors (i.e. stabilize the sludge), they are only add-on in nature.

BETA RAY IRRADIATION: Sludge is irradiated with beta rays from an accelerator at dosages of at least 1.0 megarad at room temperature (ca. 20°C).

GAMMA RAY IRRADIATION: Sludge is irradiated with gamma rays from certain isotopes, such as ^{60}Cobalt and ^{137}Cesium, at dosages of at least 1.0 megarad at room temperature (ca. 20°C).

PASTEURIZATION: Sludge is maintained for at least 30 minutes at a minimun temperature of 70°C.

OTHER METHODS: Other methods or operating conditions may be acceptable provided pathogens are reduced to an extent equivalent to the reduction achieved by any of the above add-on methods.

5.0 SIGNIFICANCE OF GUIDELINES ON B. C. PRACTICE

The general criteria for most guidelines is that the yearly quantity of sludge applied to land should be based on nitrogen requirements of the crop grown. A survey of digested sludge characteristics of various B. C. communities (Table 1) showed that we can expect Total Kiedahl Nitrogen (TKN) values to vary from 2% to 5% of sludge solids. If we assume that 220 kg of Nitrogen per hectare per year is a reasonable application to meet most crop needs then the amount of sludge applied would vary from 4 400 kg/Ha/yr to 11 000 kg/Ha/yr on a dried basis. In volume of liquid digested sludge this would be approximately 8,000 gallons to 50,000 gallons per acre per year depending on the sludge thickness as well as its nitrogen content. Table 2 shows the permissible number of yearly sludge applications for several B. C. sludges based on the maximum and minimum criteria in the guidelines studied. From the results in this table it would appear that the copper content of B. C. sludges would be the limiting factor for land application. If the most stringent criteria for copper were used the maximum number of sludge applications to land would range between 6 and 9 for many B. C. sludges. The amount of land required to dispose of any significant amount of sludge would be very large if this criteria were applied as new land would have to be found every 6 to 9 years.

In order to appreciate how much land is required for sludge application under these conditions let us consider Campbell River as an example. The sewage treatment plant at Campbell River is an activated sludge plant treating a sewage flow of 1.5 mgd. The sludge produced at this plant is 720 kg per day (dried basis). The amount of Campbell River sludge which can be applied to land (based on nitrogen application of 220 kg/Ha/yr) would be 4 783 kg/Ha/yr. The land area required therefore is:

$$\frac{730 \text{ kg/day} \times 365 \text{ days/yr}}{4\,783 \text{ kg/Ha/yr}} = 56 \text{ hectares or } 138 \text{ acres}$$

TABLE 1

SLUDGE AND COMPOST CHARACTERISTICS IN BRITISH COLUMBIA

	pH	Sp. Cond.	NH_4	NO_3	TKN	C Total	Cd	Cr	Fe	Mn	Ni	Al	Co	Zn	Mo	Pd	Cu	Ca	As	P Total	Total Residue	B
		umho /CM	mg/L	mg/L	mg/g	mg/g	ug/g	ug/g	mg/g	ug/g	ug/g	mg/g	ug/g	ug/g	ug/g	ug/g	ug/g	mg/g	ug/g	mg/g	%	ug/g
Nanaimo	7.8	4780	600	0.08	18.4	358	5	28	7	113	14	3.6	<10	643	4	198	624	13.6	<5	7.59	2.02	
French Creek	7.1	1390	7.2	0.01	46.7	304	7	28	11	618	16	5.9	14	1350	4	141	1230	24.3	<5	13.2	2.04	
Campbell River	7.0	610	30.2	0.52	46.	341	6	26	10	123	15	3.5	<10	900	3	267	949	12.3	<5	14.5	0.6	
Lions Gate (GVRD)	8.1	6850	1000	0.09	31.2	332	5	153	12	140	28	4	12	763	6	250	1830	22.9	<5	12.9	5.08	
Iona Island (GVRD)	5.7	1810	119	0.05	27.1	298	7	142	13.3	211	29	6.7	14	912	3	741	966	11.4	5	7.2	8.45	10
Central Saanich	7.2	830	47	0.03	44.1	291	4		5.6	122	15	6.1	<10	560	2	82	472	19.	5	15.4	0.66	
Maple Ridge	5.4	1070	60.5	76.9	50.5	304	6	25	7.7	221	13	4.1	<10	694	3	159	2000	16.1	<5		0.34	
Annacis Island (GVRD)	8.1	7210	1010	0.06	27.7	375	5	157	8.7	127	32	4.4	<10	1070	3	311	992	15.4	<5	13.	2.87	20
Pitt Meadows	7.1	643	34.6	0.02	63.8	405	6	20	4.9	119	12	2.7	<10	654	3	102	1100	12.2	<5	18.2	0.75	
Lulu Island (GVRD)	5.4	625	27.8	0.11	22.2	424	29	906	4.6	54	83	3.	20	1850	12	510	959	7.9	<5	3.7	3.74	
Penticton	8.1	3620	450	0.05	29.3	200	4	54	120	404	15	3.	23	648	7	153	1350	29.4	20	38.4	1.38	<10
Vernon	8.3	6710	930	0.08		261	9	55	12.7	125	27	6.	22	1140	8	416	1300	29.		14.5	1.25	20
Ashcroft	5.9	1220	44	101	32.4	238	9	40	15.3	154	25	5.8	<10	1250		187		30.2	5	19.4	0.43	
Enderby	7.3	629	27	0.05	41.1	237	4	18	3.5	72	10	2.3	<10	551	4	83	414	38.4	<5	10.8	0.17	
Cache Creek	8.0	1140	3	7.2	12.7	77	<1		34.4					250	<1	32	461	27.6	<5	4.22	1.	
Merritt	7.8	890	45	0.04	43.5	-	7	27	7.6	114	18	3.6	11	712	10	115	1480	24.	<5	14.3	0.8	
Bazan Bay					45.4		6	32	7.3		23	6.4		1380	3	123	646	33.4	8	12.0	0.4	60
Sidney					35.9		6	38	11.4		24	9.8		930	5	193	688	11.9	18	17.3	2.6	20
Kelowna (Raw Thickened)	5.5	1730	112	0.06	39.2	283	6	29	7.2	91	18	3.6	16	679	10	142	1380	16.4	5	6.5	3.1	10
Central Okanagan Compost (PCB Data)					6.5	319	2	13	4.8	171	5	2.5	17	190	3	71	319	7.6	5	1.5		12
Milorganite*	4.4		361		66.9		113.0	7150	48.2	64	67.6	4.9	8.5	984	18.6	555	941		5.9	13.3	94.5	6.8
Grow Rich					6.2	64	8	92	19.5	270	33	10.4	55	461	1	312	1160	6	5	3.15		33
Grow Rich *	5.9		1.6		2.07		0.7	43	9.7	188	19	5.4	4.3	62	<11	74	60		2	0.9	58.4	0.2
Steer Manure*	8.8				6.5		0.6	14	11.3	216	8.4	6.3	4.8	58	<12	10	17		3	3	66	4.4
Common Soils ** (Range)							0.06 (0.01 to 7)	100 (5 to 3000)		850 (100 to 4000)	40 (10 to 1000)		8 (1 to 40)	50 (10 to 300)	2 (0.2 to 5)	10 (2 to 200)	20 (2 to 100)		6 (0.1 to 40)			10 (2 to 100

* "Analysis of Grow Rich Potting Soil, Milorganite and Steer Manure" B.C. Research Report June 22, 1978

** ALLAWAY, W.H. Advances in Agronomy, Academic Press Inc. New York Vol. 20, 1968 as reported in EPS Report 4-WP-76-3 "Recycling of Liquid Digested Sludge on Dredged River Sand".

TABLE 2

PERMISSIBLE NUMBER OF YEARLY SLUDGE APPLICATIONS* USING MAXIMUM AND MINIMUM CRITERIA IN GUIDELINES STUDIED

*Assume each application applies 220 kg nitrogen per hectare

	TKN %	DRIED SLUDGE/YR kg/ha	CADMIUM MIN	CADMIUM MAX	NICKEL MIN	NICKEL MAX	ZINC MIN	ZINC MAX	COPPER MIN	COPPER MAX	LEAD MIN	LEAD MAX	CHROMIUM MIN	CHROMIUM MAX	MOLYBDENUM MIN	MOLYBDENUM MAX	COBALT MIN	COBALT MAX	ARSENIC MIN	ARSENIC MAX
Nanaimo	1.84	11,956	28	364	78	1170	17	127	9	67	28	840	200	3000	56	103	251		167	250
French Creek	4.67	4,711	52	676	173	2595	21	157	12	90	101	3030	508	7620	143	264	455		425	637
Campbell River	4.6	4 783	59	767	181	2715	31	232	15	112	52	1560	539	8085	188	348	627		418	627
Sidney	3.59	6 286	45	585	86	1290	23	172	15	112	55	1650	280	4200	86	159			88	132
Iona Island	2.71	8 118	30	390	55	825	18	135	8	60	11	330	58	870	111	205	267		246	369
Annacis Island	2.77	7 942	43	559	51	765	16	120	8	60	27	810	54	810	113	209	378		252	378
Maple Ridge	5.05	4 356	65	845	230	3450	44	330	7	52	97	2910	615	9225	207	383	689		459	688
Penticton	2.93	7 509	57	741	115	1725	28	210	6	45	58	1740	165	2475	51	94	179		66	99

If the most stringent criteria encountered in the guidelines were followed this land could be used for:

- 15 years prior to reaching the maximum allowable copper loading
- 31 years prior to reaching the maximum allowable zinc loading
- 52 years prior to reaching the maximum allowable lead loading
- 59 years prior to reaching the maximum allowable cadmium loading
- greater than 180 years prior to reaching maximum allowable loading for other heavy metals.

The Campbell River sludge has the lowest copper content of the sludges studied (in Table 2) and it still considerably limits the life of the sludge disposal site. If the copper concentration were reduced the site life would be doubled. Raw water stabilization and source control in sewers may be required to reduce copper concentrations in the sewage.

From consideration of the various guidelines:

- the copper concentrations in most B. C. sludges would appear to be a concern at this time and guidelines would restrict the application of sludge to land based on this metal.
- cadmium concentration appears to be a problem at Lulu Island however sludge at this time is incinerated at this plant. Cadmium concentrations in the rest of the sludges surveyed would not appear to be a problem.
- lead concentrations at Iona could limit application of this sludge to land.
- concentrations of nickel, chromium, molybdenum, cobalt and arsenic would not appear to be a problem at this time in any of the sludges studied.
- in most cases the limiting metal after copper would be zinc.
- with regard to boron it seems from data shown in Table 1 that under worst conditions loadings boron would not exceed 1.5 kg/Ha/yr which is well within published limits.

- due to winter conditions any time period which may be determined to be necessary prior to grazing cattle could seriously affect the application of sludge to grazing land or pasture. A six month waiting period as some have proposed could eliminate grazing for for the complete summer if sludge is applied in the spring whereas a two week or two month period would have lesser effects.

It should be noted that air dried sludge and compost have not been discussed as these will be covered in another paper. Dried sludges and compost have much less nitrogen and so the yearly loading rates are based on heavy metal criteria rather than nitrogen requirements of the crop.

6.0 SIGNIFICANCE OF EPA REGULATIONS ON B. C. PRACTICE

From a review of the recently published EPA Land Disposal Criteria it appears that sludge application to land is not based on the nitrogen needs of the crop but rather on limiting the amount of nitrate-nitrogen in the groundwater flowing from the site (maximum allowable level is 10 mg/L as N). Cadmium is the only heavy metal metal mentioned with regard to limiting the amount of sludge applied to land either on a yearly or total cummulative basis however there are pH restrictions on the soil-sludge mixture. The most restrictive EPA criteria for cadmium is less restrictive than the most restrictive criteria outlined in the guidelines studied. From the analysis presented in Section 5 it would appear that the cadmium concentration in B. C. sludges should not present any particular problems unless the digested sludge is applied at a rate far in excess of the nitrogen requirements of the crop grown. Dried sludge applications would be limited but the most stringent EPA requirements would allow application of approximately 400 tonnes of dried sludge per hectare. The provision for only producing animal feed on sludged land further reduces any restrictions with regard to cadmium loading. It is anticipated that pH requirements could be met by the addition of lime where required.

The most significant impact of the EPA Land Disposal Criteria on B. C. practice is with regard to their controls for disease. Implementation of the EPA Criteria would virtually eliminate present

sludge disposal to land practices in British Columbia. As mentioned earlier the majority of air dried sludge or compost is disposed by application to public parks, boulevards, farms, general public, etc. as an organic soil conditioner. Under the EPA Criteria, public access to any facility or land used to dispose of sludge treated to "Significantly Reduce Pathogens" which includes air dried sludge must be controlled for 12 months. Grazing by animals must be restricted for one month. These criteria also apply to the application of liquid digested sludge whether it be spread on land surface or incorporated. Composted sludge may be included in this catagory unless sufficient temperatures (i.e. 55^{o}C) are reached for a specified period of time (i.e. 15 days) during the composting period with a minimum of five turnings. However, septic tank pumpage which has been treated to "Significantly Reduce Pathogens" is not subject to similar restrictions and there is no need to control public access or animals on the site. Since B. C. practice normally does not control access (either human or animal) to the site where the sludge or compost is used such practice would not be allowed by EPA criteria except in the case of treated septic tank pumpage (i.e. composted septic tank pumpage).

If the sludge or septic tank pumpings are to be applied to land on which food crops for direct human consumption are to be grown within 18 months of application then the sludge or pumpings must be treated to "Further Reduce Pathogens". For the most part this type of treatment requires that the sludge be subjected to a controlled high temperature over a specified period of time or irradiated. At present there are no facilities in the province which are equipped to carry out this type of treatment.

It should be noted that the EPA Disease Criteria is "interim final" which means that these regulations may be subject to change. Sludge disposal practice throughout the world normally allows the reuse of digested dried sludge in an agricultural manner without restrictions on public access and from a resource recovery point of view it is to be hoped such practice can be continued as sludge treatment costs rise significantly when heat treatment or irradiation must be used in the process.

7.0 CONCLUSION

In concluding this paper I believe it is fair to state that British Columbia is in the preliminary stage of determining the extent of its sludge disposal problems and how best to utilize the sludge from a resource recovery point of view.

Aside from the problem of heavy metals and toxic organics in sludge there is the concern regarding the presence of pathogenic organisms (virus, bacteria, protozoa and parasites). While the test for heavy metals and various organic compounds may be routine, tests for pathogenic organisms and their interpretation are not so simple. The question arises as to "when is a sludge sufficiently processed such that it can be considered a resource rather than a hazardous waste?", and "how does one control the processing of sludge so as to ensure that the sludge product is in fact a resource rather than a waste?". The EPA have taken the approach of requiring specific sludge treatment processes and operating conditions prior to certain land applications and sludge usages. This approach is likely to be expensive. Is it best for B. C. conditions?

These are questions which we will undoubtedly have to address in the future.

AGRICULTURAL ASPECTS OF SLUDGE APPLICATION TO CROPLAND

BY

R. A. Bertrand
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AGRICULTURAL ASPECTS OF SLUDGE APPLICATION TO CROPLAND

R.A. Bertrand
Director, Soils Branch

1. INTRODUCTION

The mandate of the B.C. Ministry of Agriculture, and specifically the Soils Branch, is to help ensure maintenance of the long-term productivity of the provincial agricultural soils resource. Therefore, we are concerned about the application of any material or use of any management practice which may reduce the agricultural potential of our soils resource. Some sewage sludges contain heavy metals, micronutrients, and other substances which after application to cropland may reduce productivity and/or the suitability of the land for a normal range of crops.

On the other hand, the Ministry supports the recycling of plant nutrients through soils and the concept of waste recovery. Sludges contain a number of essential plant nutrients and organic matter which are required to maintain soil productivity. Sludge application to cropland is the preferred route of disposal, from an agricultural point of view, if potential chemical and biological hazards are maintained within acceptable limits.

The following discussion outlines some concerns, from an agricultural point of view, relative to application of sludge onto cropland. Specifically, the G.V.R.D. situation is reviewed in some detail.

2. REGULATION OF SLUDGE QUALITY

Since sludge contains nutrients and organic matter which are useful for crop production, regulations should be in place to prevent excess quantities of heavy metals, and any other potentially harmful compounds, from entering the sewage. However, where point-sources of heavy metal additions are not adequately controlled, regulations are required relative to maximum metal content which can be applied to cropland and number and frequency of applications to a particular parcel of land.

The Fertilizer Act, administered by the Plant Products Division of Agriculture Canada, regulates the chemical and physical properties of fertilizers and supplements which are offered for sale. The following have been tentatively accepted as maximum acceptable metal concentration in processed sewage, sewage-based products, and other by-products with 5% or less total nitrogen. These limits, when finalized will be added to the Regulations of the Fertilizer Act.

Metal	Maximum Acceptable Concentration in Processed Sewage
Arsenic	75 ppm
Cadmium	10 ppm
Cobalt	150 ppm
Chromium	1100 ppm
Copper	850 ppm
Mercury	5 ppm
Molybdenum	20 ppm
Nickel	180 ppm
Lead	500 ppm
Selenium	14 ppm
Zinc	1850 ppm

Maximum acceptable metal concentrations are based on a cumulative total application of 200 tonnes per hectare of a 5% N product. A 5% total nitrogen product applied at 220 kg N per hectare would attain the following acceptable maximum metal additions to soil in 45 years.

Metal	Maximum Acceptable Metal Addition to Soil (kg/ha)
Arsenic	15
Cadmium	1.6
Cobalt	30
Chromium	220
Copper	168
Mercury	0.9
Molybdenum	3.8
Nickel	36
Lead	94
Selenium	2.7
Zinc	363

The Fertilizer Act does not control materials which are not offered for sale. Therefore, most sewage sludges and sludge-based products are not regulated as to metal content. British Columbia will have to adopt regulations which are similar, if not identical, to those in the Fertilizer Act before routine application to cropland can be considered.

3. APPLICATION OF G.V.R.D. SLUDGE TO CROPLAND

Currently the Ministries of Agriculture, Health, and Environment are cooperating on a program to monitor metal levels in sludge and sludge-wood waste compost from the Greater Vancouver Regional District sewage plant at Iona Island. Following is average metal content of 6 dried sludge samples obtained in January 1980 compared with Milorganite and the proposed Fertilizer Act maximum levels.

Metal	Iona Sludge (ppm)	Milorganite (ppm)	Proposed Fertilizer Act Maximum Metal Levels (ppm)
Cd	13.8	113	10
Cr	161	7150	1100
Ni	47	67	180
Zn	746	984	1850
Mo	4.7	18	20
Pb	720	555	500
Cu	934	341	850
As	5		5

The Iona sludge exceeds the proposed Fertilizer Act levels for Cd, Pb, and Cu. However, if composted with wood waste at a ratio of 1:1, the material would be acceptable. Milorganite, a soil supplement containing 6% nitrogen, contains about 9 times more cadium and 44 times more chromium than Iona sludge, and far exceeds the levels to be established.

Many guidelines for sludge application recommend rates of application on the basis of nitrogen content of the sludge and nitrogen requirement of crops. The Iona sludge and the composted material are

both very low in nitrogen (approx. 1%) and nitrogen to metal ratios are low. If applied to cropland, nitrogen supplementation would be required as sludge application rates would not be able to supply sufficient N without exceeding metal limits.

4. LAND AVAILABLE FOR SLUDGE DISPOSAL - G.V.R.D.

Sewage sludge from the Greater Vancouver Regional District is of immediate concern relative to method of disposal. Most sludges from other areas are lower in metal content and the volume is much less and, therefore, application to land poses fewer problems.

The two largest treatment facilities, located on Annacis and Iona Islands, produce about 10,000 tonnes of sludges (on a dry weight basis) per year; 5,000 tonnes from each. Assuming an application rate of 4.4 tonnes per hectare per year (Fertilizer Act regulations); about 2,300 hectares of land are required for disposal of this sludge. Depending on the frequency of application to any one hectare of land, the required base for a land disposal program is about 10,000 hectares.

In the municipalities of Richmond and Delta there are close to 18,000 hectares in the Agricultural Land Reserve plus some hectares of park and other public lands. In close proximity to the Annacis site are 3,000 hectares of agricultural land in East Richmond. Thus, in Richmond and Delta there is sufficient land for disposal, however, there are many factors which may reduce the accessible area significantly. These include: grower and public acceptance of sludge on cropland, type of crops grown, transportation and handling equipment and costs, and frequency of application allowable.

5. RECOMMENDATION

a) In most instances land application of sludge is preferable to other disposal methods such as land filling, incineration, or dumping into water. Therefore, regulations should be adopted to prevent addition of metals to sewage which will limit the usability of sludges for crop production.

b) The land base for sludge application is very limited in the G.V.R.D. If sludge with excessive metals is applied to cropland, the option of land disposal will be rapidly eliminated. All agencies must cooperate to reduce metal additions to sewage.

c) The Ministry of Environment should add to the regulations of the Pollution Control Act maximum levels for metal content of sludge and sludge-based products. Consideration should be given to using the same levels as those to be added to the regulations of the Fertilizer Act.

COMPOSTING OF RAW SLUDGE WITH FOREST INDUSTRY WASTE

BY

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COMPOSTING SEWAGE SLUDGE WITH FOREST INDUSTRY WASTE

Kelowna, like every city with a sewage treatment plant, has been faced with increasing costs and diminishing returns when dealing with the disposal of its sewage sludges. The generation of greater amounts of sludge by increasingly more sophisticated methods of sewage treatment have put many cities on a merry-go-round of higher costs for ultimate disposal of their wastes. The search for the least expensive disposal system has developed the approach where sludge is treated as a nuisance, to be swept under the carpet, rather than a resource to be carefully managed. Some examples of this are:

1. Incineration -- which is very capital, energy and labour intensive.
2. Ocean dumping -- which just transfers the problem from the source to the ocean.
3. Landfilling -- which hopes by burying the sludge it will stay out of sight and out of mind.

Each of these examples solve the short term problem; however, come back to haunt you with a lack of a long term solution. However, treatment technologies have existed for many years where sewage sludges can be converted into useful end products which can be recycled into our environment in a beneficial form. The main reason these alternatives have been ignored is their costs; however, with the escalating costs of conventional methods of sludge disposal (and their long term effects), some cities need to re-evaluate their sludge disposal strategy. Until recently the costs of incineration may have been cheaper than operating a composting project; however, with increased energy and labour costs composting can compete economically and is the more cost effective method if an end use for the product exists.

The City of Kelowna started like many communities with a small sewage treatment plant which anaerobically digested its sludge, then dried it in gravel drying beds. Home gardeners and local farmers would come and pick up the end products and provided

they did not over-dose their gardens or farms, this practice proved very satisfactory. The City does not have industrial input to its sewage system, thus heavy metals are not a major problem, and this disposal technique could have remained a long term solution. However, the City grew and the sewage volumes increased, thus larger plants were built until one day there simply was too much sludge to be properly digested and dried with existing facilities. At this stage an economic evaluation was done of the state of the art of sludge disposal methods and in 1970 the City started incinerating its sludge. This was very nice until OPEC arrived and energy costs escalated rapidly and accompanying this was the aging of the incineration system and subsequent increased maintenance costs. Thus when major repairs were due in 1978, the City was ready to start evaluating alternative sludge disposal practices, especially if they were less expensive than incineration and this started the composting experiment.

I would like to spend a few minutes explaining the general operational parameters of composting before I deal specifically with the techniques used in Kelowna. First, I would like to offer a definition of sludge composting that I have borrowed from a text. "Composting is a method of solid waste management whereby the organic component of the solid waste stream is biologically decomposed under controlled conditions to a state in which it can be handled, stored and/or applied to the land without adversely affecting the environment." The key words are biologically decomposed, organic components and under controlled conditions. Various types of composting systems fit the above definition; however, most can be classified by the following three categories:

1. Aerobic or Anaerobic - normally composting is kept aerobic by blowing air through the compost mixture or by adding sufficient bulking agent to entrap air. The aerobic process is much quicker and has far less odors; however, it can be more expensive depending on the method used to keep oxygen at a surplus.

2. Mesophillic (10° C - 45° C) or Thermophillic (45° C - 70°C) -this deals with the temperature in the mixture and generally speaking, if you keep oxygen present your temperature will be in the thermophillic range. This can be very useful in reducing the concentration of pathogenic bacteria.

3. Mechanical or Windrow - mechanical implies the use of stirred or rotating containers to keep the material well mixed and aerobic, while windrow implies mixing first, then letting the material stand while the organisms do their work.

The aerobic and thermophillic method is by far the most popular and this is combined in a windrow system in Kelowna.

The composting process is biological, thus the key environment factors are the same as other biological treatment systems. The concentration and availability of the following components are the key to successful operation of the process.

1. Carbon - is used as an energy source for the micro-organisms or in simple terms - carbon is the food. The carbon source chosen should be readily degradable material in order to promote a rapid breakdown and thermophillic temperatures. The carbon source material is one of the keys to sewage sludge composting and if you have an inexpensive supply, your project can become cost effective. Some examples are garbage, leaves, winery, brewery, food industry wastes or wood wastes, such as is used in Kelowna.

2. Nitrogen - Nitrogen is the other major key to successful operation of a compost pile. The carbon/nitrogen balance is most important and if this balance is more than approximately 30 parts carbon/1 part nitrogen, then nitrogen becomes the limiting nutrient and the organisms' activity will decrease and the temperatures will not go as high.

3. Phosphorous and Trace Elements - when using sewage sludges these nutrients are not normally a problem; however, the organisms require these nutrients the same as carbon and nitrogen and if they are deficient, then reaction rates will again be sub-optimal.

4. Water - the micro-organisms require water and the % moisture of the compost mixture is also important. Below 50% the lack of moisture can become the limiting factor. Above 90% the excess moisture may hamper the transfer of oxygen and turn the compost mixture anaerobic.

5. Oxygen - the continued presence of oxygen is important to maintain the growth of the aerobic organisms which generate the thermophillic temperatures. Oxygen deficiency would result in reduced activity and thus reduced temperatures.

6. Temperatures - when all the above factors are provided in their required concentrations, the compost mixture will quickly heat up. Temperatures in the thermophillic range would be difficult to avoid and may reach up to 70° C where the biological activity actually decreases. However, temperatures above 50° C are most beneficial in reducing pathogens and in activating seeds.

The carbon source used in the Kelowna composting operation comes from a local sawmill operation which uses "hog fuel" as a fuel source for its boilers which generate electricity for the plant operation. Hog fuel is produced in excess of normal mill requirements, thus is trucked off-site for disposal which appears to be a common problem in many locations in B.C. This "hog fuel" makes an excellent carbon source for composting due to its ability to act as a bulking agent which entraps enough oxygen to keep the process aerobic. The hog fuel is trucked to the site where it is shaped into elongated lagoons with approximately 1 metre bottoms and 2.5 metre side walls. Loading ramps are built on one end and the sludge is trucked from the treatment plant and dumped into the lagoons.

The sludge from the treatment plant is gravity thickened raw sludge of approximately 5% solids content. In order to achieve the required carbon/nitrogen ratio of 30/1 using this raw sludge, it would be necessary to add such a large quantity of sludge that the hog fuel would virtually be drowning in water. Thus the problem was how to deal with the excess water. The first alternative would be to centrifuge the sludge prior to hauling; however, this would be costly, both from a capital and operating standpoint. The second alternative was to try dosing the hog fuel with all the water it would hold and compost the mixture even though it would be nitrogen deficient. This was tried and compost temperatures quickly reached the 50^{o} C - 55^{o} C level, despite the nitrogen limiting situation. The compost piles were left to stand and surprisingly very few odors developed and after approximately one month the temperatures started subsiding. Knowing the mixture was still nitrogen deficient we decided to dose the pile a second time and found that following mixing, it again reached thermophillic temperatures. This process was repeated a third time and again temperatures reached the thermophillic range; however, they stayed in that range for a longer period of time, suggesting the nitrogen limiting situation had been overcome.

With the success of the first pile some estimated annual operating costs were developed and even with conservative figures the annual cost appeared lower than the existing cost of incineration. Thus in July of 1979 the incinerator was shut down and the City decided to try the composting operation for its sole method of sludge disposal.

The composting site chosen was adjacent to the City's sanitary landfill operation and this was not by accident. The problem of how to restore the landfill site to an agriculturally viable condition had long been a problem. There was plenty of clay and sand available; however, it would require a good soil conditioner to produce a good soil for farming. Thus the composing product fit the requirements and with a market already created, the site adjacent to the landfill operation was chosen.

To date the biggest problem has been determining the amount of water/sludge mixture to add to the hog fuel to end up with the desired % moisture in the composting windrows. One or two of the first group of lagoons were over-dosed and subsequently several problems developed. Towards the end of the dosing some water leached out of the lagoon and during mixing the mixture simply had too high a % moisture. With too high a % moisture the windrow slumped during the windrow stage and the centre of the pile went anaerobic. This did not cause an odor problem until the pile was opened up to prepare for the second dosing and the odor quickly dissipated after it was exposed to more oxygen. The excess water problem occurred with only 2 of the first 5 lagoons, thus we assumed the sludge/hog fuel mixture was on the borderline of an excess. The second set of 5 lagoons, which are now finished, were dosed with slightly less sludge and the excess water situation has not repeated itself.

The hog fuel supply has not been confirmed with a long term commitment by the sawmill; however, I am confident if they fail to provide us with the quantities required, there are other sources in the Kelowna area. At present the excess hog fuel is a disposal problem for the sawmill and they are paying approximately one-half of the trucking cost.

The trucking of sludge and hog fuel and the supply of rental equipment for lagoon building and mixing has not been a problem. To date we have agreements for the sludge trucking and hog fuel supply and have rental equipment from local contractors for mixing.

The estimated annual operating costs are listed below, with the project handling approximately 500 dry tons of sludge per year:

Hog Fuel Supply	$10,000
Sludge Hauling	40,000
Lagoon Mixing	6,000
Lagoon Building	4,000
	$60,000/year - 500 tons = $120/tons

This will provide approximately 15,000 yards/year of composted material depending on the carbon/nitrogen ratio we eventually choose to use. The current market value of similar material for agricultural use would cost $4 to $5 per yard. This will help offset the cost of the project and may eventually break even on sludge disposal costs.

Two final questions may arise from use of the compost product and they are:

1. What about heavy metals?
2. What about pathogenic organisms and virus?

The Kelowna sewage system, as previously mentioned, does not allow industrial connections that would contribute significant quantities of heavy metals and thus the heavy metal concentration is typical for domestic sewage wastes. However, even domestic sewage produces significant quantities of heavy metals and this must be monitored. Following preliminary lab results the heavy metal problem appears to amount to balancing the dose rate of the composting material to a limiting metal concentration, probably cadmium. However, with a controlled restoration project such as resurfacing a landfill operation the City can remain in control of dose rates and even monitor the crops produced if the need arises.

The concerns of bacteria and viruses can be answered with the same response. With the reclamation site controlled by the City, public access can be eliminated and with the planned 6-month minimum time lapse between treatment plant and land spreading following composting, a large portion of harmful organisms will be destroyed by thermophillic temperatures and natural die-off. However, with the windrow composting techniques, I would not be confident of sufficient pathogen and virus reduction to allow re-sale to home gardeners without additional time lapse from treatment plant to public contact.

These two concerns of heavy metals and bacteria/viruses

will evolve more clearly as research into composting techniques continues. I trust one day we will have the answer because at present there exists a market that would turn this sludge disposal project into a money maker. That market is the home gardener and many transport garbage to the dump with their pick-up trucks and return home empty.

I will leave you with that thought - I realize the Kelowna situation may be unique; however, it is worth investigating in other communities that may have a similar forest industry waste.

A PRESENTATION OF THE MUNICIPALITY OF METROPOLITAN SEATTLE (METRO) SLUDGE UTILIZATION RESEARCH

BY

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INTRODUCTION

This paper will present a chronological and topical summary of Metro programs conducted on sludge utilization since 1971 and their findings. For the sake of clarification, the projects are divided into the following categories: 1. soil rehabilitation, 2. fertilization, and 3. energy recovery. Major findings on projects dealing with agriculture, fertilizer processing, silviculture and composting will be presented. Controlling issues which influence the successful utilization of municipal sludge are identified as follows: 1. handling and sludge processing, 2. supply and demand factors, and 3. regulatory constraints.

Conventional biological municipal sewage treatment processes try to replicate those processes which occur over much greater distance in natural river systems. One unique difference between the two processes is that solids are flushed out of the river system during spring floods while in the sewage treatment process solids are mechanically removed. Sludge "solids" from a municipal treatment plant are 0.5 to 3.0 percent solids and have the appearance of "black water." Because of the handling problems and cost associated with the large volume of this "black water," additional treatment through digestion and dewatering is often undertaken.

The digestion process reduces the volatile solids thereby reducing the odor and fly breeding potential of the sludge. Also, limited quantities of methane gas may be recovered from this process and used to meet some of the energy demands of the treatment plants. Dewatering, with the use of retention ponds, lagoons, drying beds, centrifuges, vacuum belts and filter presses, usually concentrates the sludge to about 20% solids. The trend towards large capacity centralized sewage treatment plants has recently increased the magnitude of the sludge handling problem. Early practices of spreading sludge on land adjoining the treatment plant have become less acceptable with increased competition for land use. A common practice among ocean dischargers in the past has been to discharge digested sludge solids through offshore effluent outfalls. Some United States east coast municipalities barge the liquid sludge out to ocean disposal dump sites.

The 1972 Federal Clean Water Act (P.L. 92-500) identified as a national goal the elimination of ocean dumping of municipal sludge. The Marine Protection Research and Sanctuary Act (P.L. 92-532) as amended in November 1977 (P.L. 95-153) prohibited all dumping of municipal sludge after December 13, 1981. The United States Environmental Protection Agency (EPA) subsequently published ocean dumping criteria on January 11, 1977. By 1973, the reported discharge of sewage sludge into the ocean in the United States had increased from 4,477,000 tons in 1968 to 5,429,000 tons. In 1977, EPA estimated that the 18,000 publicly-owned treatment plants (POTW's) were generating approximately 5,000,000 dry tons of sludge per year and that they expected this

figure to double within ten years as a result of secondary treatment requirements. In 1977, EPA estimated that landfills were receiving 25% of the municipal sludges, land applications were utilizing 25%, 15% was disposed of in the ocean, and 35% by incineration. On September 15, 1979 the Resource Conservation and Recovery Act of 1976 (P.L. 94-580) established criteria for improving the operation of sanitary landfills and closing open dumps. In April of 1979 EPA estimated a 75% increase in disposal costs would be necessary to bring sludge landfills into compliance, thus disposal costs could increase from $12.00 to $20.00 per wet ton. The classification of sewage sludge lagoons as open dumps eliminated the opportunity to store sludge for decanting, drying or stabilization. A series of deadlines identified in the above federal laws indirectly calls for elimination of all open dumps by October, 1983.

On September 13, 1979, EPA published very specific interim final sludge guidelines for agricultural use. These regulations limit annual cadmium loading rates to 0.5 kilograms per hectare on land use for tobacco, leafy vegetables, or root crops grown for human consumption. Other food crops can receive up to 2.0 kilograms per hectare until June 30, 1984 but must meet the 0.5 level by 1987. The pH for food chain crops must be above 6.5 and future property owners must be notified by stipulation in the property deed that a site has received solid waste with high cadmium application rates and that food chain crops should not be grown due to possible health hazards.

The full impact of these stipulation and other regulations on commercial farmland application of municipal sludges has yet to be felt. The reaction to these agricultural sludge use restrictions have ranged from the banning of all sludge-grown products by canneries, to challenging the legality of such criteria by municipalities. In the fall of 1979 the Citizens for a Better Environment (CBE) filed a petition with the Consumer Product Safety Commission requesting a ban of the use of aged sludge from the City of Chicago ("New Earth") "and all other sewage sludge sold or distributed to consumers because they are hazardous products," charging that EPA did not intend to put sludge distribution and use regulations into effect until 1981.

On November 27, 1979, EPA deferred revisions on emission standards for sludge incinerators due to their inability to reliably meet cadmium and total solids emission standards of the clean air amendments to the Federal Air Quality Act of 1967 (P.L. 90-148). The availability and cost of fuel for incineration may eliminate this option in the near future. Incinerator ash disposal is further complicated by increased solubility of metal oxides which have been concentrated in the incinerator ash.

The Municipality of Metropolitan Seattle (Metro) was formed in 1965 to divert primary and secondary effluent discharges from Lake Washington into Puget Sound via the West Point Primary Treatment Plant.

The present collection system--pumping stations and five treatment plant locations--is presented in Figure 1. Effluent which is discharged into the Green-Duwamish River from the Renton Treatment Plant receives secondary treatment while the sludge from that treatment plant is pumped into West Point for digestion and dewatering. From 1965 to 1971 the primary sludge was discharged with the effluent through a 3,650-foot long 230-foot deep marine outfall. Comprehensive investigations of the outfall indicate a rapid dispersion of sludge and effluent. In 1971, Metro agreed to stop the discharge of sludge into Puget Sound in response to public concern over unknown effects which might result from those discharges.

In view of the rapidly changing sludge processing technology, energy demands, and regulatory changes, Seattle Metro developed an interim sludge strategy of testing the feasibility of as many sludge utilization options as possible. Since 1971, Metro has spent over $1.4 million on sludge-related research projects, excluding handling and site costs. Approximately $870,000 of those costs were funded directly by the Municipality. A multitude of dewatering, drying, reprocessing, soil building, soil rehabilitation, agricultural, and forest applications of municipal sludge were tested by Metro (Table 1). Much of the research undertaken by Metro was done on a demonstration scale and frequently involved the use of more than 50% of the annual sludge production. In 1980, Metro will spend approximately $1.3 million to dispose of 60,000 tons of 20% sludge solids from its service population of 850,000 people. Long-range planning, equipment, and prototype site acquisition is anticipated to cost an additional $850,000 during 1980.

OBJECTIVE

The objective of this presentation is to give a chronology of Metro sludge utilization experiences, discussing the major findings from these studies, and to describe what appear to be the controlling issues regarding future sludge utilization.

DEFINITION

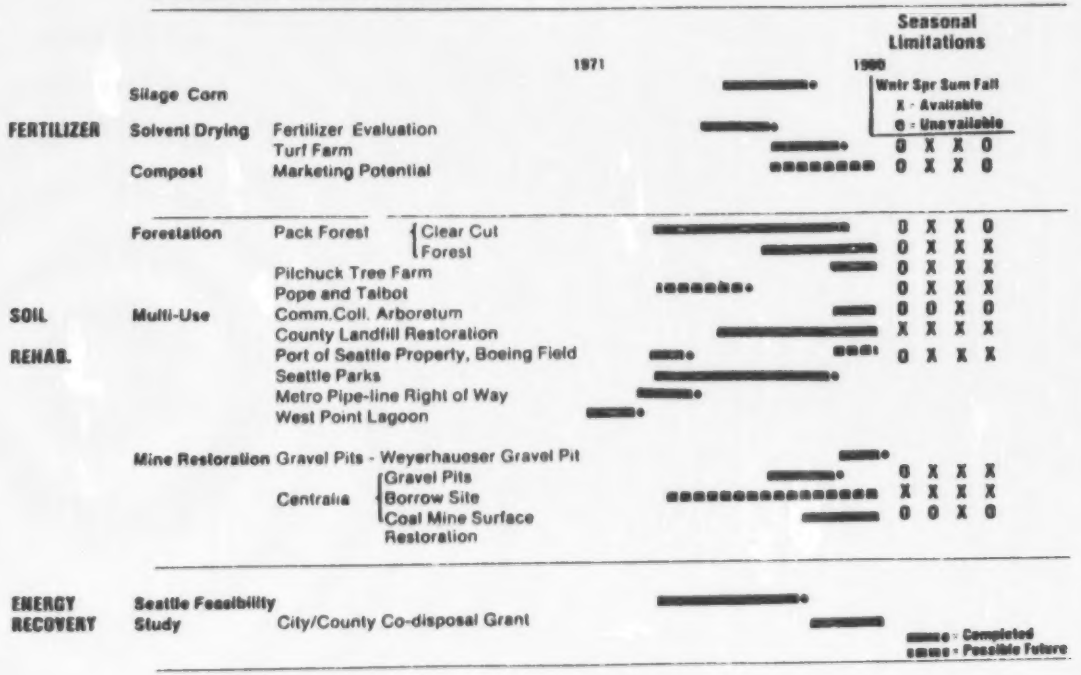
Fertilizer:

The categories of sludge utilization warrant further definition. Metro has taken the position that the application of sludge primarily as a source of major nutrients should be categorized as a "fertilizer" application. Fertilizer application rates normally are governed by the annual plant uptake of nitrogen. While the available nitrogen in municipal sludges varies considerably, application rates of sludge as a fertilizer may be governed by federal regulations on heavy metal loading.

Figure 1. Municipality of Metropolitan Seattle (Metro) Collection System.

Table 1

SLUDGE UTILIZATION PROJECTS



Soil Rehabilitation:

The phrase "soil rehabilitation" was coined by Metro to describe those projects where sludge application rates intentionally exceeded the major nutrient needs of plants. The purpose of these heavier applications of dewatered sludge or composted sludge is to replace natural organic soil components on grossly disturbed sites. This approach provides substantial opportunities in reforestation projects, strip mine restoration, landfill overburden revegetation and large landscaping projects. The specific advantages of these heavier application rates are the increase in organic content in the soil, improved tilth, increased moisture retention, erosion resistance, and positive plant growth responses.

Energy:

The energy recovery category includes the production of burnable gases via biological processes in anaerobic digesters, or chemically produced through incineration of the organic carbon. Pyrolysis is a process for producing a burnable gas from sludge through gasification in a starved air incinerator. This partial incineration or gasification of dried sludges produces a low-quality gas that has some industrial applications. Co-disposal systems utilizing separated combustible portions of municipal solid waste are often described as methods of drying sludge to the 30-40% solids range necessary to support combustion.

PROGRAM FOCUS

The efforts of Metro to utilize sludge have concentrated on soil rehabilitation, sludge handling, fertilizer use, and fertilizer processing. Metro's efforts to utilize sludge have been very diverse, with the greatest effort over the past 8 years on silvicultural research. The Municipality has also helped in the development of several parks and investigated several energy recovery systems, including the Union Carbide and Jet Propulsion Laboratory pyrolysis systems.

Metro studies have demonstrated both beneficial effects and potential liabilities with nearly all of the projects studied. A variety of problems ranging from plant responses, chemical/energy cost, groundwater contamination, site management costs, consumer acceptance, and weather limitations have been identified. Tables 2, 3, 4 and 5 list in a synoptic manner, the advantages and disadvantages associated with disposal, agriculture, soil rehabilitation, and energy recovery systems respectively. In Figure 2, the average annual sludge production of Metro is plotted on a monthly basis. When compared with the seasonal availability of potential sludge projects (Table 1) it is clear that over 40% of the sludge produced must be handled during the

TABLE 2

SLUDGE DISPOSAL

	ADVANTAGES	DISADVANTAGES
OCEAN	1. Conserves energy 2. Least public health exposure risk 3. Nutrients available to plants and animals 4. Year around reliability 5. Least operating cost	1. Legality an issue 2. Potentially disruptive to marine life through tomicants or over-fertilization 3. Poorly designed systems may allow nearshore contamination of shellfish
LAGOONS	1. Year around access 2. Self-sealing against leachate 3. Bacterial dieoff over several years 4. Aging and drying possibilities in some climates 5. Low capital cost	1. Discouraged under present regulations (RCRA P.L. 94-580) 2. Accumulate water in some climates 3. Odors (particularly from undigested sludge) 4. Cost to build or empty lagoons
SANITARY LANDFILL	1. Legally most acceptable 2. Confines environmental impacts on site 3. Year around access	1. High per ton cost 2. Possible leachate flow increase 3. Production ratios of sludge to solid waste vary widely
INCINERATION	1. Small ash volume to be ultimately disposed 2. Can eliminate sludge hauling	1. Air pollution emissions often exceed allowable standards 2. High operating cost 3. High capital cost 4. Requires substantial dewatering or alternate fuel to dry prior to incineration

TABLE 3

SLUDGE UTILIZATION IN AGRICULTURE

	ADVANTAGES	DISADVANTAGES
DIRECT FIELD APPLIED SLUDGE	1. Potentially cheap fertilizer 2. May provide needed trace elements to soil 3. May require fewer natural resources to produce than commercial fertilizer 4. Some crops respond better to sludge than to commercial fertilizers	1. Regulatory constraints on allowable crops and subsequent land use 2. Crop contamination from bacteria, virus and heavy metals 3. Handling problems with conventional farm equipment 4. Seasonal needs vary more than sludge supply 5. Regulated sludge use must compete with unregulated fertilizer use 6. Difficulty in finding enough farm land near larger municipalities 7. High cost per dried ton of sludge solids
PROCESSED SLUDGE FERTILIZER	ADVANTAGES	DISADVANTAGES
	1. Improves handling and storage 2. Less risk to public health from bacterial contamination 3. Improves sludge "image"	1. Increased processing cost (often exceeds incineration cost) 2. Labeling recommendations discourage potential users 3. Seasonal needs vary more than sludge supply 4. Capital intensive and frequently resulting in higher operating cost as well

TABLE 4

SLUDGE UTILIZATION FOR SOIL REHABILITATION

ADVANTAGES	DISADVANTAGES
1. Creates more revegetative possibilities	1. Nitrate leaching may exceed drinking water standards
2. Physically improves soil moisture retention, tilt, & erosion resistance	2. Intensive site management must be coordinated with weather constraints
3. Least costly land application per dry ton of solids	3. Lack sufficient all-weather site opportunities
4. Regulatory flexibility when non-agricultural crops are grown	

TABLE 5

SLUDGE UTILIZATION FOR ENERGY

	ADVANTAGES	DISADVANTAGES
METHANE PRODUCTION	1. Cost-effective net energy producer 2. Process improves dewatering and reduces both odors and percent volatile solids 3. Does not expend energy to remove water 4. Relatively less critical operating process than other energy systems	1. Quality of gas does not lend itself to storage or export 2. Requires large digestion tanks to handle the low solids loading
PYROLYSIS	1. A method of disposal without complete loss of energy 2. Opportunity to use separated solid waste as a "combined" fuel	1. High capital and operating cost 2. Gas product is market- and user-limited 3. Low heat yield 4. Gas impurities 5. Emission gas scrubbing water requires treatment

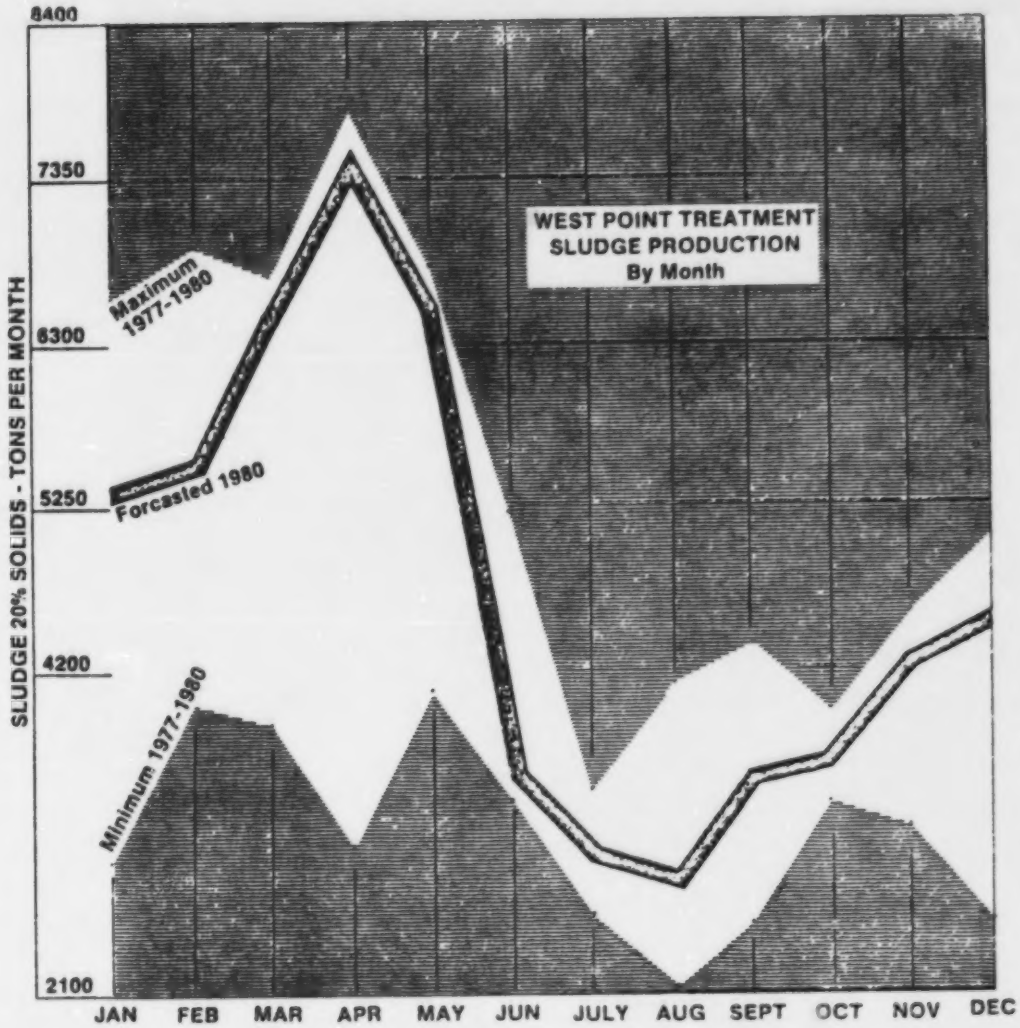


Figure 2

Municipality of Metropolitan Seattle (Metro)
Annual Sludge Production

winter months when there is the least opportunity for sludge utilization. This constraint necessitates a diversity of sludge handling options and temporary "fall back" solutions including landfilling and lagoon storage, especially during winter treatment plant operation. Table 6 summarizes research results in chronological order, starting with the sludge landfill development in 1971 and ending with the completion of a gravel pit restoration project in 1979. The project schedule, application rate, equipment used and approximate cost are also included.

Agricultural

Agricultural research was conducted for Metro by Washington State University (WSU), Western Washington Agricultural Research and Extension Center located in Puyallup, Washington. Results were published in March of 1979. Their findings are based on two years of research on sludge applications on Sultan silty loam and Puyallup fine sandy loam soils. Demonstration plots were also undertaken west of Mt. Vernon, near the Skagit Extension Center of WSU. In one study rye and silage corn were planted on limed and unlimed soils with sludge, fertilizer, and replicate control plots. Sludge application rates were 22.4 dry metric tons per hectare. The objectives of this study were to demonstrate the fertilizer value of sludge in commercial crop production in western Washington, to determine sludge application rates for optimum crop production and the heavy metal status of soils and crops from addition of sewage sludge, and to evaluate potential environmental hazards, including those associated with nitrate (NO_3^-) leachate and from coliform and fecal coliform bacteria. Soils were limed from a pH of 4.7 to 6.5. The dewatered sludge which was used for this study was analyzed at 19% total solids, 3.7% total nitrogen, and 0.6% NH_4^+-N (ammonium ion-nitrogen). The experimental design is shown in Figure 3.

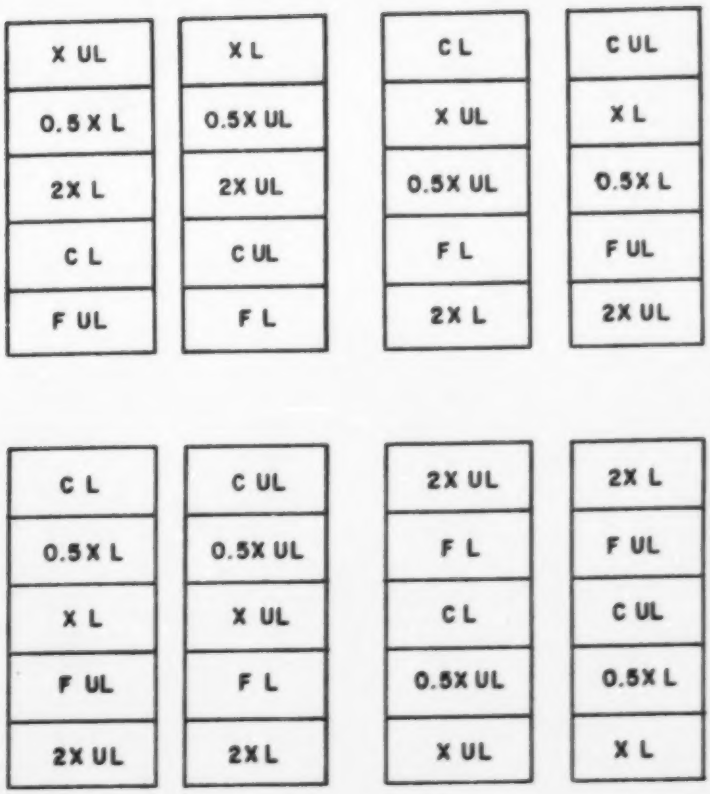
After a fall sludge application, plots were sown with a winter cover crop of rye grass (Lolium multiflorum) which was harvested the following April of 1976 and 1977. After the rye harvest, all plots received a fertilizer "guide" application of 25 kilograms of nitrogen, 21 kilograms of phosphorus, and 65 kilograms of potassium per hectare. The fertilizer plots received an additional 220 kilograms of nitrogen per hectare. Plots were then planted in silage corn and harvested at maturity in September of both years. No consistent coliform die-off trend was observed in the data between those soils limited to a pH of 6.5 and those allowed to remain at 4.5. Winter rye yields varied widely for each sludge application rate. All rye yields were equivalent to those based on recommended fertilizer rates. Maximum silage corn yields also varied, with the sludge loading rate of 44.8 to 89.7 dry metric tons per hectare being the optimum in the first year and that of 22.4 dry metric tons being optimum in the second year.

Table 6
Chronology of Sludge Activities

PROJECT NAME	LOCATION	DATES	QUANTITY	APPLICATION RATE	% SOLIDS	EQUIPMENT USED	APPROX. COST ($/dry ton)
Puget Sound Outfall	3,690' offshore from West Point plant at depth of 230'	1966-1972	9,000-11,000 dry tons	Via 600' diffuser section; ports at 6' intervals	less than 3%	Diffuser and outfall lines	$6.00
Beach front earth fill park development	Beach lagoon adjacent to West Point plant on south shore	1971-1973	2,500 dry tons	Layers of sludge and sand to depth of 12'	50%	Dump trucks, clam shell dredge, loaders, graders and scrapers	$60.00
Cedar Hills Regional Landfill	7 miles southeast of Renton	1973-1980	3,200-8,000 dry tons	Stored in 16' deep lagoons and applied at 8" application to landfill overburden	20%	25-30 cubic yd. trucks, scrapers and drag line, and 36" construction disk for tilling overburden, 103,000 cubic yds. of lagoon storage capacity	$57.00-$145.00
Issaquah Interceptor Right-of-Way Restoration	East of Issaquah River and north of Lake Union	4/73-5/73	1,000 dry tons	160 wet tons at 3-7 inch depths as a soil conditioner	20%	Bulldozer, trucks, a 4-bottom plow, 25-30 cubic yd. trucks	$80.00
Gasworks Park	North end of Lake Union in the City of Seattle	spring 1974	1,100 cubic yds.	6-8 inches in depth including sawdust and partially composted sludge	25%	25-30 cubic yd. trucks, bulldozer and tractor-pulled roto-tiller	$85.00 (excluding site cost)
Boeing Field Airport	Duwamish River industrial area of Seattle	1974	1,300 cubic yds.	less than 1 inch used as soil rehabilitation	approx. 25%	25-30 cubic yd. trucks, bulldozer, and tractor-pulled roto-tiller	$80.00 (excluding site cost)
Pier 86 Grain Terminal Park	Northeast shore of Elliott Bay	1975	1,400 dry tons	4-6 inches	20%	25-30 cubic yd. trucks, bulldozers, graders, front-end loaders, and tractor-puller roto-tiller	$80.00 (excluding site cost)
Pope and Talbot Forest Lands	4 miles west of Hood Canal floating bridge site south of highway 104	1973	21 dry tons	10, 20, 50 and 100 dry tons to the acre sprayed on 1/10 acre plots with a water cannon	approx. 4%	Enclosed tanker trucks, 6" water cannon mounted on forest-type fire fighting vehicle	$275.00 (reflects cost of hauling liquid sludge via Wash. State ferries)

Table 6
(continued)

PROJECT NAME	LOCATION	DATES	QUANTITY	APPLICATION RATE	% SOLIDS	EQUIPMENT USED	APPROX. COST ($/dry ton)
Pack Forest	Near Eatonville, west of Mt. Rainier	1974-present	18,000 dry tons (approx.)	In clearcut areas applied to depths of 6-18 inches; in forest stands application rates of between 2" and 4" at 6 mo. intervals	20%	25-30 cubic yd. trucks, D7 and larger bulldozer, 36" construction disk, specialized water cannon	$85.00-$123.00 $125.00-$147.00 for pumper applications
Weyerhaeuser-University of Washington (EPA Grant)	Weyerhaeuser land adjoining Pack Forest	1975-1978	1.5 dry tons	Over the canopy with nozzle water cannon, spray irrigation, and trickle irrigation of 4 acres	4%	Enclosed tanker trucks, water cannon, spray irrigation system, sprinkler heads, macerating pump, screen and storage tanks	$220.00
Washington State University Agricultural Research (3 sites)	3.5 miles east of Puyallup; 1.5 miles west of Kent; and, 3 miles west of Mt. Vernon	1975-1977	total of 40 dry tons	Applied annually on farm land at the rates of 10, 20 and 40 dry tons/acre	20%	20 cubic yd. haul trucks, manure spreaders, wheeled and tracked tractors, conventional 12" disk	$116.00
Renton Compost	Renton sewage treatment plant	1975	15 dry tons	Mixed with wood chips, steer compost, grass and wood chip pruning debris in 5' high windrows	25%	Front-end loader	$130.00
IroCo Compost	2 miles north of Kent in Duwamish Valley	1979	2,400 dry tons annually	Mixed 4:1 and 3:1 with sawdust and windrowed to 15' high	22%	7.5 cubic yd. front-end loader and Lindig shredder and 40' conveyor belt	$97.00
Turf Farm	5 miles north of Sumner	1978	180 dry tons	1/2"-2"	20%	25-30 cubic yd. trucks, farmer-used conventional disk and wheeled tractor	$76.00 (excluding application and on-site management)
Grouse Ridge Borrow Pit	10 miles east of North Bend and 3 miles north of I-90	1979	12,000 dry tons	Between 9" and 36"	20%	D7 bulldozer, 36" construction disk, grader, front-end loader and 25-30 cubic yd. trucks	$110.00



KEY:

Lime: L Limed
U Unlimed

Sludge: C Control
F Fertilizer
0.5X 22.4 dry metric tons / hectare
X 44.8 dry metric tons / hectare
2X 89.7 dry metric tons / hectare

Figure 3 Plot diagram used for the Puyallup and Sultan soils in the 1976 and 1977 growing seasons. Bezdicek (1979)

The change in optimum application rates was attributed to a residual sludge fertilizer benefit from the previous year's application. The lime appeared to stimulate mineralization and the uptake of sludge nitrogen, increase silage yields by about 1 metric ton per hectare and consistently reduced concentrations of both zinc and cadmium in all forage crops. Concentrations of both silage zinc and cadmium doubled proportionately with each doubling of sludge application up to the loading of 89.7 dry metric tons per hectare (Table 7). With the second addition of sludge, the increase in zinc and cadmium in the silage was 10 times that of the control. At the recommended sludge rate of 22.4 dry metric tons per hectare cadmium concentrations in the silage were four times as high as the control. At the lowest application rate the corn kernels had considerably lower zinc and cadmium concentrations than other parts of the plants, with a difference of 0.4 parts per million in the kernels and 2.7 parts per million in the complete silage (Table 8). Cadmium concentrations in plant tissue tended to be twice as high in the Sultan as compared to the Puyallup soils (Table 8).

On the Mt. Vernon sweet corn plots maximum yields were obtained at the lowest sludge application rate, and those yields were below the fertilizer "guide" plot yield. In the spring of 1976, a broccoli crop was planted on all sludge plots. The resulting crop was normal in color and growth, but had few marketable heads. The failure of that crop was attributed to excessive nitrogen mineralized from the previous sludge application. The study concluded that the 22.4 dry metric tons per hectar (10 tons per acre) may be optimal for maximum silage yield with slightly higher rates required during the first year. Leaching of nitrates into the groundwater are probably no greater than from rates of fertilizer currently used. Dairy cattle consuming silage grown on sludge increased their dietary cadmium intake four-fold if the silage were produced on plots where sludge had been applied at the lowest rate studied. Cadmium concentrations in corn kernels were 7 to 10 times lower than in the silage at an equivalent sludge application rate. The kernels of corn grown on sludge are a safer feed source than the whole plants relative to cadmium concentrations.

Published federal regulations on agricultural practices would result in allowable annual applications of cadmium of 1.78 lbs per acre until 1984, 1.12 lbs per acre from 1984 to 1986, and 0.45 lb. per acre after 1987. Based on the Metro sludge cadmium concentrations of 64 ppm as published in 1976 (Table 9), the allowed agricultural loading rates would be 13.9 tons of sludge per acre, 8.7 tons of sludge per acre, and 3.5 tons of sludge per acre for the same time periods described above. Table 9 also documents the cadmium concentrations for other major cities in the United States. These data illustrate the dilemma most major cities would have in applying enough sludge to meet crop nitrogen needs without exceeding allowable cadmium loading.

Table 7 Influence of sludge rate, lime and soil type on Zn and Cd content of corn silage in 1976 and 1977. Bezdicek (1979)

	Zn		Cd	
Sludge[1/]	1976	1977	1976	1977
dry metric tons per hectare	ug/g			
0	30.0	39.3	0.6	0.6
22.4	55.0	98.3	1.3	2.7
44.8	97.3	211.4	2.1	3.6
89.7	142.1	375.4	2.9	6.3
Fertilizer Guide	31.1	39.7	0.7	0.8
Liming[1/]				
Limed	74.5	124.1	1.4	2.7
Unlimed	82.6	181.5	1.6	2.9
Soil Type[1/]				
Sultan soil	94.2	154.0	2.1	3.7
Puyallup soil	62.9	151.5	0.9	1.9

[1/] Means of four replications are pooled over all other variables studied.

Table 8 Influence of sludge rate, lime, soil type and year on Zn and Cd content of corn tissues. Bezdicek (1979)

Sludge dry metric tons per hectare 1/	Leaves		Stover		Cobs		Kernels	
	Zn	Cd	Zn	Cd	Zn	Cd	Zn	Cd
	µg/g							
0	37.6	1.0	32.0	0.9	37.3	0.3	37.1	0.2
22.4	118.5	4.4	94.1	3.2	59.2	0.7	42.2	0.4
44.8	238.5	6.2	224.7	4.9	84.0	0.9	65.3	0.5
89.7	420.7	8.6	384.9	8.0	132.5	1.2	91.3	0.5
Fertilizer Guide	44.0	1.1	44.0	1.2	39.2	0.3	33.8	0.2
Liming 1/								
Limed	134.6	4.1	121.4	3.4	56.4	0.5	45.7	0.3
Unlimed	209.1	4.4	185.5	3.8	78.6	0.5	49.2	0.4
Soils 1/								
Sultan	159.6	5.7	164.7	4.9	62.8	0.8	54.7	0.5
Puyallup	184.1	2.8	142.3	2.3	72.2	0.5	40.2	0.3
Year 1/								
1976	128.0	3.0	92.6	2.4	49.6	0.6	37.4	0.4
1977	215.6	5.5	214.3	4.8	85.5	0.7	57.5	0.3

1/ Means of four replications are pooled over all other variables studied.

Table 9. Concentrations of Elements and Chlorinated Hydrocarbons Found in Various Municipal Sludges and Cow Manure
Furr et al. (1976)

	Chicago	Denver	Los Angeles	Milwaukee	New York	Seattle	Washington, D.C.	Cow manure
	- Concentration - parts per million in dry weight of solids -							
*Dieldrin	0.24	0.16	0.44	0.05	...	0.10	...	<0.01
*PCB[b]	11.60	1.60	4.00	2.20	...	0.50	...	<0.01
*Arsenic	29	14	26.0	3.3	8.0	30.0	6.6	4.0
Boron	44	30	90	30	50	40	16.0	23.5
Barium	623	632	1066	344	417	504	892	268
*Beryllium	<6	<10	<11	<4	<12	<7	...	
*Cadmium	14.8	46.1	171.4	443.7	29.7	64.0	31.0	0.8
*Chromium	207	936	4925	14000	646	1320	1260	56
*Copper	578	1370	2890	1288	1890	1170	458	62
Fluorine	297.6	48.0	198.8	49.5	5.1	2.2	...	6.6
*Mercury	6.1	3.6	7.1	3.4	15.0	8.2	5.8	0.2
Magnesium	95	224	116	134	152	350	323	286
*Nickel	51.2	562	402	360	140	153	...	29
*Lead	605	1011	3065	2253	1976	2411	498	16.2
*Selenium	1.7	3.5	8.7	1.7	2.7	2.7	1.9	2.4
Tin	166	161	209	133	202	373	291	3.8
Strontium	259	262	360	94	334	186	...	81
Titanium	2380	1340	3170	1580	2050	2560	4260	2800
*Zinc	1160	2860	4590	1370	1340	1830	1475	71

* On 1978 EPA Priority Pollutant List
b Determined as Aroclor 1254.

	- Concentration in % dry weight of solids -							
Aluminum	1.36	1.34	1.74	0.81	1.29	2.70	5.12	2.88
Calcium	2.53	1.55	4.01	0.86	1.61	2.64	2.40	26.4
Chlorine	0.10	0.39	0.39	0.22	0.85	0.22	0.34	0.18
Iron	0.88	8.28	2.07	4.30	2.12	2.71	4.50	1.59
Potassium	0.72	3.97	0.47	0.84	3.30	1.56	0.71	3.29
Magnesium	0.54	0.33	0.57	0.50	0.60	0.82	0.55	0.73
Nitrogen	3.99	3.14	2.19	5.80	...	2.62	...	1.25
Sodium	0.36	0.18	0.68	0.16	1.54	0.88	0.11	4.92
Phosphorus	1.60	1.32	2.08	1.84	...	1.80	...	0.90

Fertilizer Process

Two fertilizer processes which Metro has evaluated were the solvent-drying process developed by the Resource Conservation Company and a conventional wood and sawdust composting operation under the trade name of GroCo.

The evaluation of the dewatered triethylamine solvent-dried municipal sludge was funded by EPA grant No. R805584010. A Tait Andritz 20-inch belt filter press was used to thicken sludge at the Renton treatment plant for both the basic extractive sludge treatment (BEST) drying and a heat-dried sludge. Raw waste activated sludge at 0.7% solids and a 1.4% solids blend of primary and waste activated sludge were used to produce a total of 200 pounds of each product. The BEST pilot plant (Figure 4) reduced the moisture content to 11% or less. The pilot plant was operated at an average rate of 34 gallons per hour with potassium hydroxide additions of between 4 and 12 grams per liter to assist in the solvent distillation process. The triethylamine solvent (TEA) has a boiling point of 90° C and is only soluble in water below 18.7° C. Based on the pilot plant operation, a full-scale plant would require 6.86×10^6 BTU's per ton of input (at 16.6% solids) and 645 kilowatt hours per ton. Blended primary and secondary sludges with an input feed of 22.2% solids had an energy requirement of 5.37×10^6 BTU's per ton and 494 kilowatt hours per ton. An additional chemical costs of $26.00 per dry ton and $20.00 per dry ton, respectively, would be required for the waste activated, and primary and waste activated blended sludge. While there were no significant differences in the nutrient content between the BEST dried and conventional heat dried sludges, the N-P-K ratio for waste activated sludges and primary secondary sludges was 7-7-2 versus 5-5-2, respectively.

The greenhouse experiments were conducted by Washington State University using Ephrata and Puyallup soils to evaluate the BEST and conventional dried primary and secondary municipal sludges. Dr. Dave Bezdicek in an unpublished report to Metro indicated that the "agronomic potential of BEST dried sludges was not significantly different from that of conventionally dried sludges as determined by barley and chard yields in the greenhouse. The higher potassium content of the BEST dried sludges (2%-4%) may influence yield potential if applied to potassium-deficient soils. The uptake of zinc and cadmium in barley appeared to be related to the application rates, however, the cadmium uptake in chard decreased at all rates of BEST dried sludges while it increased with the conventionally dried sludges. The soluble salts were slightly higher in the BEST dried sludges, but soil electrical conductivity remained nearly the same. The soluble salts could be a critical problem for salt-sensitive crops grown in arid regions. Based on preliminary data, the formation of nitrosamines from the triethylamine solvent were not considered to be a significant problem

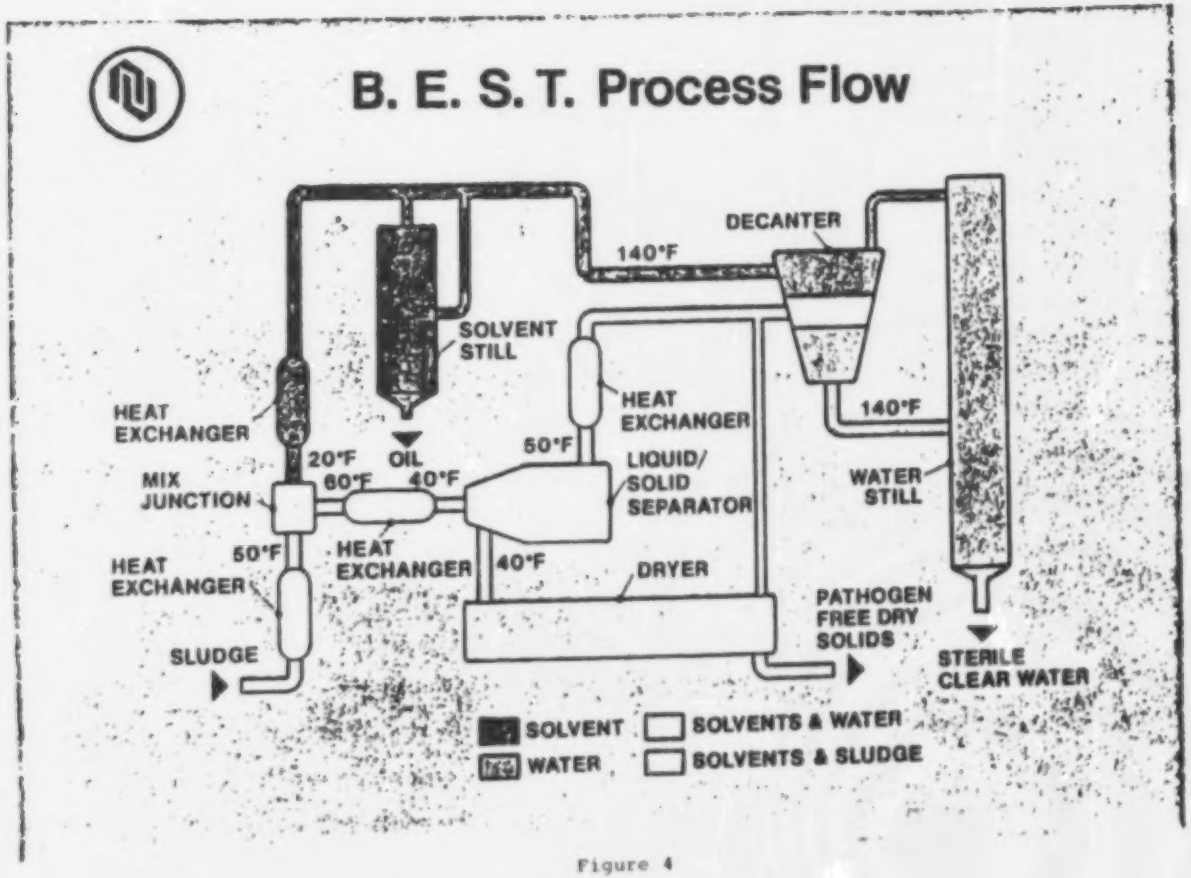

B. E. S. T. Process Flow
DECANTER
140°F
SOLVENT STILL
HEAT EXCHANGER
HEAT EXCHANGER
140°F
20°F
OIL
50°F
LIQUID/ SOLID SEPARATOR
MIX JUNCTION
60°F
40°F
WATER STILL
50°F
HEAT EXCHANGER
40°F
DRYER
HEAT EXCHANGER
PATHOGEN FREE DRY SOLIDS
SLUDGE
STERILE CLEAR WATER
SOLVENT
SOLVENTS & WATER
WATER
SOLVENTS & SLUDGE

Figure 4

but will warrant further study.

Several years of compost experimentation with a variety of bulking agents, composting aids, and compost pile management have been undertaken by Metro. A test program was conducted in 1978 and 1979 using 3,000 cubic yards of dewatered digested sludge from the West Point primary treatment plant. As described by Bruce Rennie in his 1980 report to Metro "Composting of Municipal Sewage Sludge," dewatered digested 18% sludge was delivered to GroCo in 5 discrete batches which were windrowed with fir or hemlock sawdust in ratios of 3:1 and 4:1. A Catepillar #966 front end loader with a 7½ cubic yard bucket was used to rough mix the sawdust and sludge in windrow piles approximately 12 feet high. Several batches received a loading rate of 1 pound of agricultural lime per cubic yard of compost. After 30 days of composting the piles were run through a Lindig shredder (capable of handling 125 cubic yards per hour) and windrowed via conveyer belt. After an additional 30 to 60 days the surface layer of each pile was skimmed and turned into the core of the pile. The temperature for a typical batch (Figure 5) often exceeded 150° F. The 4:1 sawdust-to-sludge ratio reached temperatures as high as 160° and tended to stay 15-20° higher than the 3:1 sawdust-to-sludge ratio. The low surface-to-volume ratios of the large compost piles were essential in maintaining high compost temperatures. Adding urea in the ratios of 1 and 3 pounds per cubic yard did not produce significantly higher temperatures during the composting. Dr. Caroline Bledsoe of the College of Forest Resources of the University of Washington has conducted a series of experiments using Metro sludge compost. Dr. Bledsoe determined that the total nitrogen in the composted end product is relatively high but it is not converted to a usable form fast enough for the deciduous and coniferous tree seedlings tested. Douglas fir sawdust and sludge in a ratio of 3:1 with a pH of 4.4 had the highest available nitrate followed by the same ratio at a pH of 5.5, while Douglas fir/hemlock sawdust-to-sludge ratios of 4:1 had less than half the available nitrates of the lower ratio. Tree species tested included: Douglas fir (Pseudotsuga menziesii), Sitka spruce (Picea sitchensis), Western red cedar (Thuja plicata), Ponderosa pine (Pinus ponderosa), Western hemlock (Tsuga heterophylla), and Poplar (Populus spp.). The response for each species (Figure 6) varied with time, but Western red cedar and Poplar had the poorest response while Douglas fir, Sitka spruce and Ponderosa pine all did better. The Sitka spruce appeared to have the best conifer response to both sludges, fertilizer, and compost treatments. The black cottonwood produced the greatest biomass for all species tested.

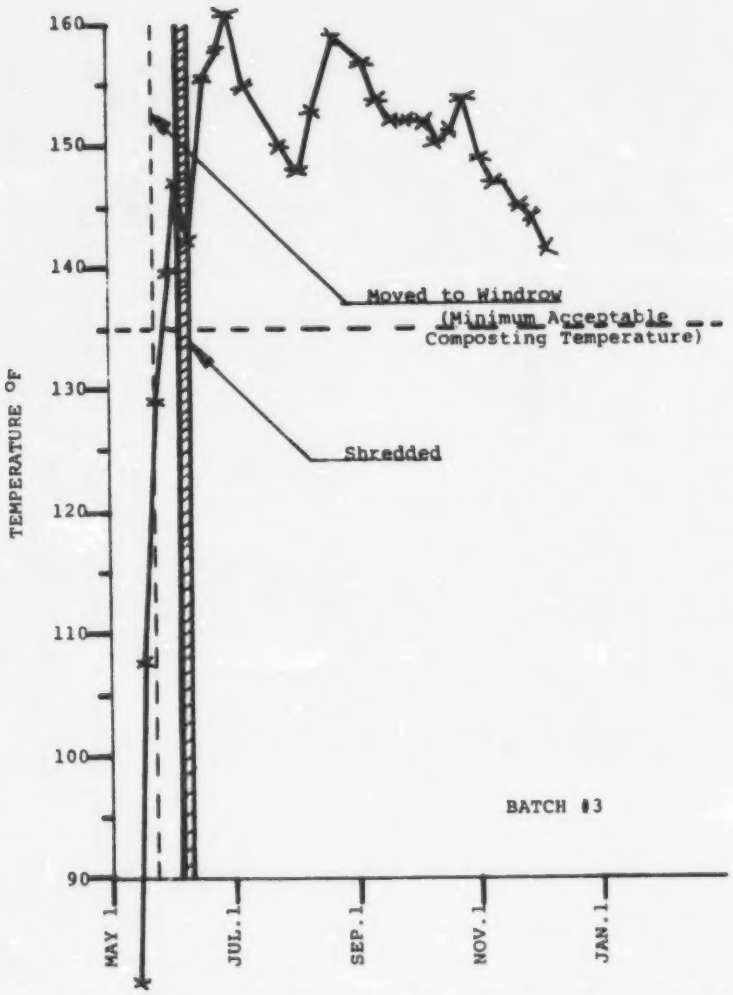


FIGURE 5 COMPOSTING TEMPERATURE AS A FUNCTION OF TIME (1978 - 1979)
Rennie (1980)

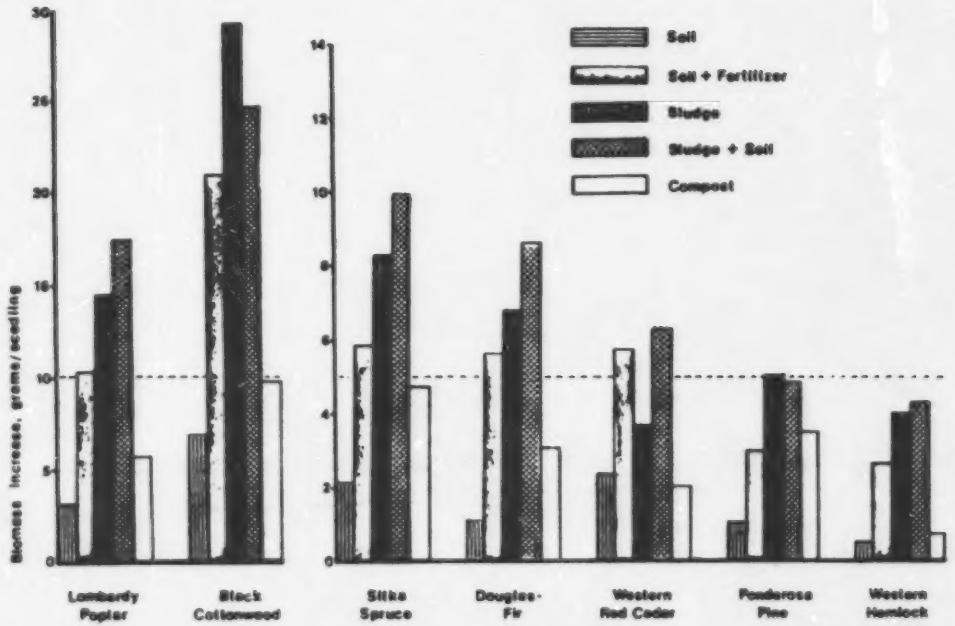


Figure 6 Biomass increase for five conifer species and two poplar species grown in soil, soil plus fertilizer, sludge, sludge plus soil and composted sludge. Bledsoe (1979)

The composting process developed by GroCo has produced a high quality composted product with a substantial coliform dieoff rate (Figure 7) but its marketability remains unproven. Market acceptance seems to be severely hampered by the voluntary labeling requirements which Metro recommended to the compost producer (see Table 10.) The label is based on the rigorous assumption that heavy metal concentrations will not be greater than heat dried sludges applied to vegetables with a high capacity for metal uptake. Because of recent market demands for sawdust as an alternate fuel source, experimentation is now underway with the use of previously composted sludge as a bulking agent for future compost production. This approach would have the advantage of increasing available nitrogen but the disadvantages of higher moisture content and higher heavy metals concentrations per unit volume of composted end product.

Soil Rehabilitation Utilizing Municipal Sludges

When sludge is used to rehabilitate soils the primary objective is to produce a soil capable of supporting vegetation which could not have been grown otherwise. The soil restoration activity diversifies the ultimate use options for the rehabilitated site. While it is possible that one of those ultimate uses might be producing crops for human consumption, this is usually not the primary intention, for the application rates would probably exceed allowable heavy metal loading for food chain crops.

Those soils which are the best candidates for a soil rehabilitation project have lost most of the organic content normally characteristic of the active soil zones and therefore have reduced their ability to retain moisture or to support vegetation. The list of soil rehabilitation projects which Metro has undertaken is categorized by the original site use and not its use after restoration (i.e. strip mine, gravel pit, parkland, and reforestation). The use of a restored site is dependent upon many variables including: ultimate economic factors, location, and public interest in each site. The strip mine reclamation projects have the greatest need and commitment for assistance in soil rehabilitation. Developing parklands can frequently provide economic benefits in sludge hauling cost due to their proximity to both the public and the treatment plants generating the sludge.

In the Pacific Northwest, forest applications of sludge provide the greatest variety of sites farthest from population centers. Ground instability during inclement weather restricts most mining reclamation projects to summer months, with the possible exception of some gravel pits. While coal mining sites may provide some cost-effective opportunities, gravel pits of less than 10 acres are

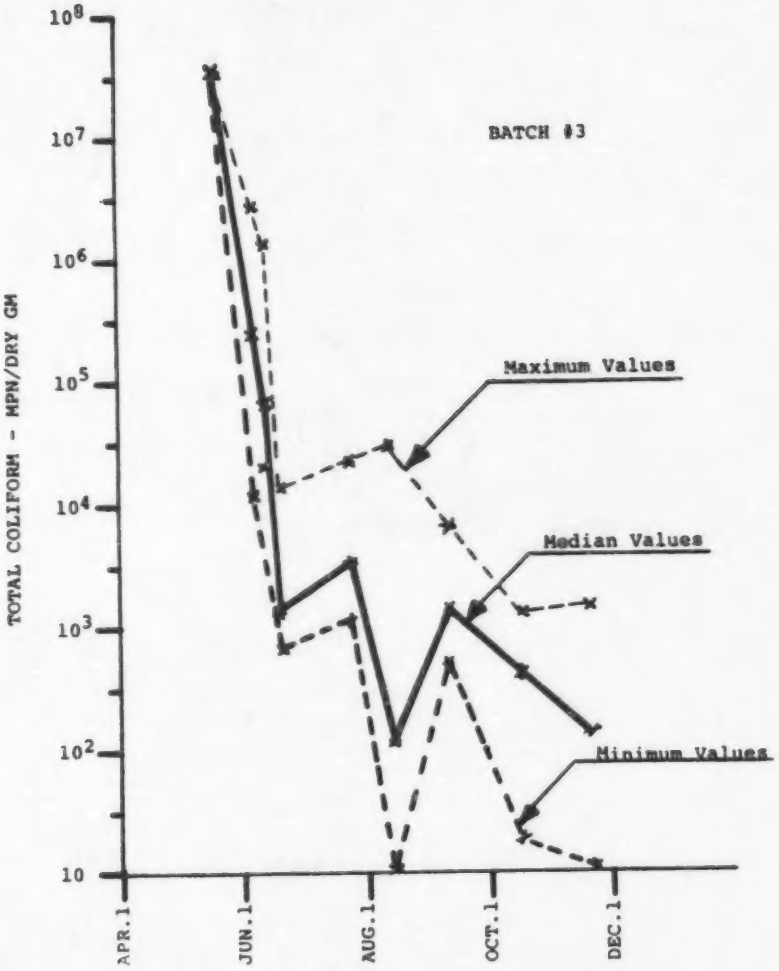


FIGURE 7 TOTAL COLIFORM DIEOFF - 1978
Rennie (1980)

Table 10

GroCo, Inc. 1016

P.O. BOX 85502
SEATTLE, WASHINGTON 98108
(206) 622-5141

DATE _____ 19___

PHONE _____ TIME _____ AM PM

INTENDED USE
- ☐ LANDSCAPING
- ☐ FOOD CROPS
- ☐ OTHER _____

☐ PD P.O.#

I HAVE READ THE REVERSE SIDE OF THIS INVOICE AND UNDERSTAND THE PRECAUTIONS.

SEE REVERSE SIDE FOR PRECAUTIONS TO BE USED WITH THIS MATERIAL

WARNING

GroCo is derived by composting digested sewage sludge under controlled conditions in sawdust. GroCo composting processes have undergone extensive bacteriological tests indicating few harmful bacteria to be present in GroCo. However, the following precaution are recommended:

- GroCo can be applied annually to a depth of 1/2 as a soil conditioner for food crops.
- GroCo must be incorporated into the soil 6 months prior to planting root crops, low growing vegetables, fruits or berries which are used for human consumption.
- GroCo handlers should use proper hygenic precautions.
- GroCo, although not a fertilizer, provides certain components needed for good soil conditioning.
- GroCo purchasers must provide the above information when dispensing to other parties.

GroCo Inc. makes no representations or warranties, expressed or implied, as to the condition of the product or as to its fitness for any purpose.

GROCO INVOICE

frequently not cost-effective.

In the Seattle area opportunities for park use of sludge have been in the development of new parklands. The potential for such sites to meet the needs of large municipalities is limited and depends on the continual development of new parks. Once a park site has been restored utilizing sludge, they have received a high level of public acceptance. However, the public is often unwilling to allow an existing park to be closed for an extended period of time as required under federal regulations when sludge is applied. When on-site problems have occurred they have been related to sludge applications and tilling during adverse weather conditions. Critical management aspects in the development of parklands are minimizing odor, restricting public access and achieving adequate sludge/soil incorporation on the site.

Although forest utilization of sludge can provide the greatest range of options to the municipality, they require more intensive site management than normal reforestation projects. Metro has identified a number of problems and solutions associated with applying either liquid or digested sludge in forest or clearcut environments. As a result of 8 years of research with the University of Washington College of Forest Resources at Pack Forest, several sludge handling methods have been identified. Weed, rodent and browsing problems on seedlings have had a major impact on otherwise positive tree growth responses. Liquid sludge irrigation on Weyerhaeuser and Pope and Talbot forest land, has led to the identification of several sludge handling problems. The major problems with liquid sludge irrigation are related to pumping system reliability, cost, and nitrate mobility.

This report does not attempt to cover all of the research activities but only the essential points. In the past eight years of research over 100,000 yards of sludge was applied to a variety of forest soils testing different management techniques. One of the first attempts at applying sludge in a forest environment was on Pope and Talbot land on the Olympic Peninsula. A series of 1/10th acre plots received an aerial spray application of 4% sludge solids equivalent to 10, 20, 50 and 100 dry tons of sludge per acre. A water cannon was used to apply the sludge over the canopy of second growth timber. The variety of age classes, species of trees, and small size of plots resulted in making a final determination on the growth benefits unclear. The heavier application rates (100 dry tons per acre) apparently sealed the ground, but within 1½ years the resultant puddles had decomposed and returned to a natural condition. Dr. Robert Zasoski et al., 1977 indicated that in spite of an increased nitrogen level, the foliage did not have a corresponding growth increase. This could be attributed to a shock of loading effect of the aerial applications. Needle growth was as much as 60% greater on some branches while others had remnants of the sludge

adhered to the needles thereby retarding the respiration and photosynthetic process.

In 1975 Metro received an EPA research grant (Number R802172) to study the use of irrigation systems for applying liquid sludge under an existing forest canopy. The project was conducted by Dr. David Wooldridge from the University of Washington, College of Forest Resources. The objective of this study was to determine what benefits to Douglas fir stands might result from the nutrients and moisture in the liquid sludge. The site was characterized by a rapid drainage of the gravelly "Everett soil" on a Weyerhaeuser site west of Mt. Rainier. In this area the growth of trees is typically moisture-limited during summer months. Weekly deliveries of digested primary sludge at 5% solids were screened and pumped through conventional Rain Bird oscillating sprinklers. Extensive piping and maintenance was required on the 4-acre site. The maximum application rate of 2" per week, or the equivalent of 38 dry tons per acre per year, apparently clogged the soil. A variety of irrigation and monitoring techniques were conducted to determine the fate of metals, viruses, bacteria and nutrients. The forest soils retained between 32% and 99% of the nitrates in the sludge during the first year. The nutrient flux was measured to a depth of 2.1 meters (7 feet) and the highest concentrations of nutrients in the soil solution coincided with the lowest soil moisture and soil solution flow rates. Tree growth based on individual plot data did not differ significantly. Data based on paired individual trees did show significantly increased diameter growth rates over controls.

The University of Washington College of Forest Resources owns a 3,000 acre research tract "Pack Forest", west of Mt. Rainier. The Center for Ecosystems Studies of the College has studied silvicultural application of sludge and effluent over the past eight years. The original objectives of these Pack Forest studies were to identify how much sludge could be applied to a clearcut site, how the sludge should be incorporated into the soil, what type of tree growth would result, and what the chemical impact was on the environment. The University developed use of 12-36 Rome construction disk plow for effectively tilling into the soil up to 18" sludge applications. The technique of tilling dewatered sludge on hillsides proved to have the additional benefits of producing an erosion resistant soil mixture.

In the process of substantially improving the vegetation on clearcut sites, several major forest management constraints were identified. These were the difficulty of tree seedlings to effectively compete with the lush weed growth that resulted, increased rodent populations which killed large numbers of seedlings by consuming significant amounts of their bark, and the preference of deer for browsing on the sludge-grown tree seedlings over the trees grown on the control plots. As the management cost of clearcut operations increased

the need for developing techniques for applying sludge under existing forest canopies that were not subjected to the weed and wildlife competition became more evident. As a result of that need, the University developed a sludge handling and pumping system which is capable of applying sludge under the existing forest canopy. This technique might also expand the range of seasons and forest topography eligible for sludge applications.

Findings under each of the above objectives were published by the Center for Eco-Systems Studies, College of Forest Resources at the University of Washington in Volume 3 of their report "Use of Dewatered Sludge as an Amendment to Forest Growth", January, 1980 by Dr. Robert Edmonds and Dr. Dale Cole. The objectives of utilizing digested dewatered sludge at Pack Forest focused on the issues of land application, management, public health implications, and plant physiology. In the category of site management, the objectives included identifying the best candidate sites for receiving sludge, determining how those sites should be managed, and determining the species best suited to the sludge applied sites. This was done under the direction of Steven Archie at Pack Forest. The cost associated with alternate procedures of sludge handling was studied by Dr. Gerard Schreuder. Dr. Jan Jorgensen and Charles Nichols solved many of the engineering problems associated with applying sludge to various terrain . Wildlife populations which impacted the forest productivity of the sites were studied by Dr. Richard Taber.

The fate of heavy metals in soils vegetation and wildlife was studied by Dr. Robert Zasoski. Nitrates and groundwater chemistry on the forest sites were studied by Dr. Dale Cole, Dr. Hans Riekerk Kristiina and Daniel Vogt. The plant physiology focused on establishing a growth response of various species of trees and determining the sludge decomposition rates to evaluate the nutrient availability to the forest vegetation. These studies were done by Dr. Robert Edmonds, Dr. Caroline Bledsoe and Kevin Mayer.

A flat glacial outwash and a residual soil (Figure 8) were both tested at Pack Forest. The glacial outwash had the greatest seasonal availability for heavy equipment. Sludge had been applied to both forested and cleared areas of these soil types. Sludge application rates of up to 16" of dewatered digested sludge resulted in elevating the nitrate levels in the groundwater as shown in Figure 9. An intermediate ground cover crop, such as rye grain in the cleared areas, decreased nitrate leaching hence this practice is recommended for reforestation of clearcut areas. The optimum sludge application rate and timing to minimize nitrate leaching remains to be demonstrated.

The Foresters anticipate that vegetation and rodent control will have to be practiced in the clearcut application for up to four years.

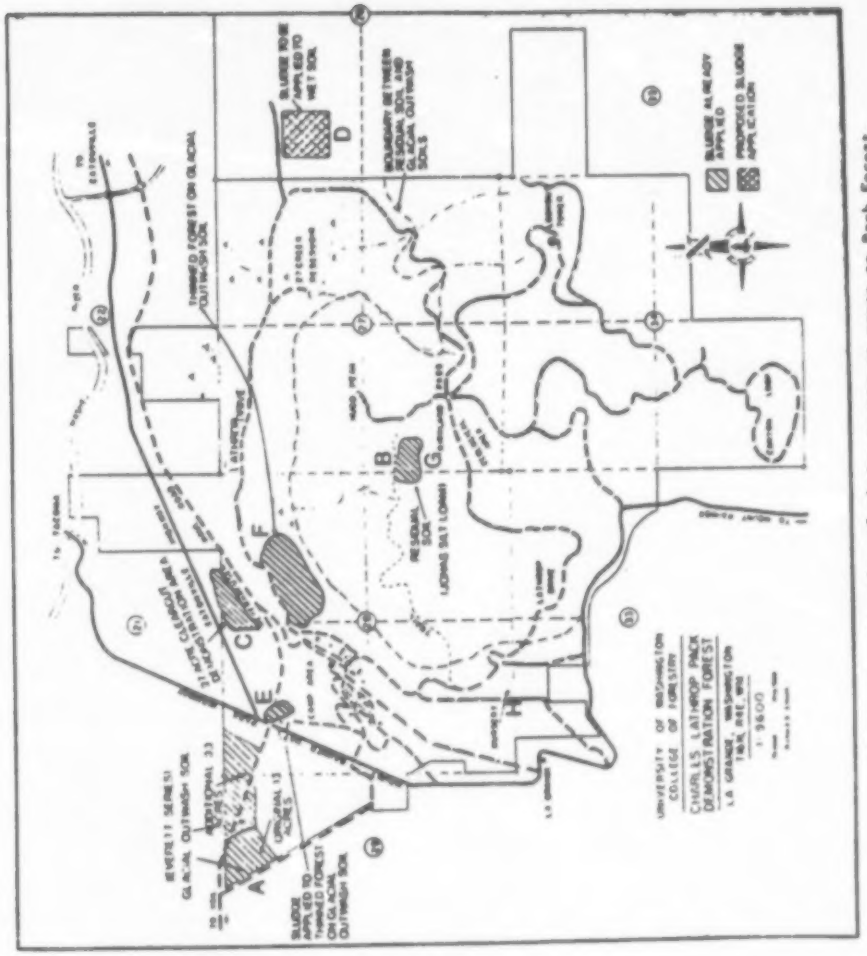


Figure 8 Location of sludge treatment areas on Pack Forest.

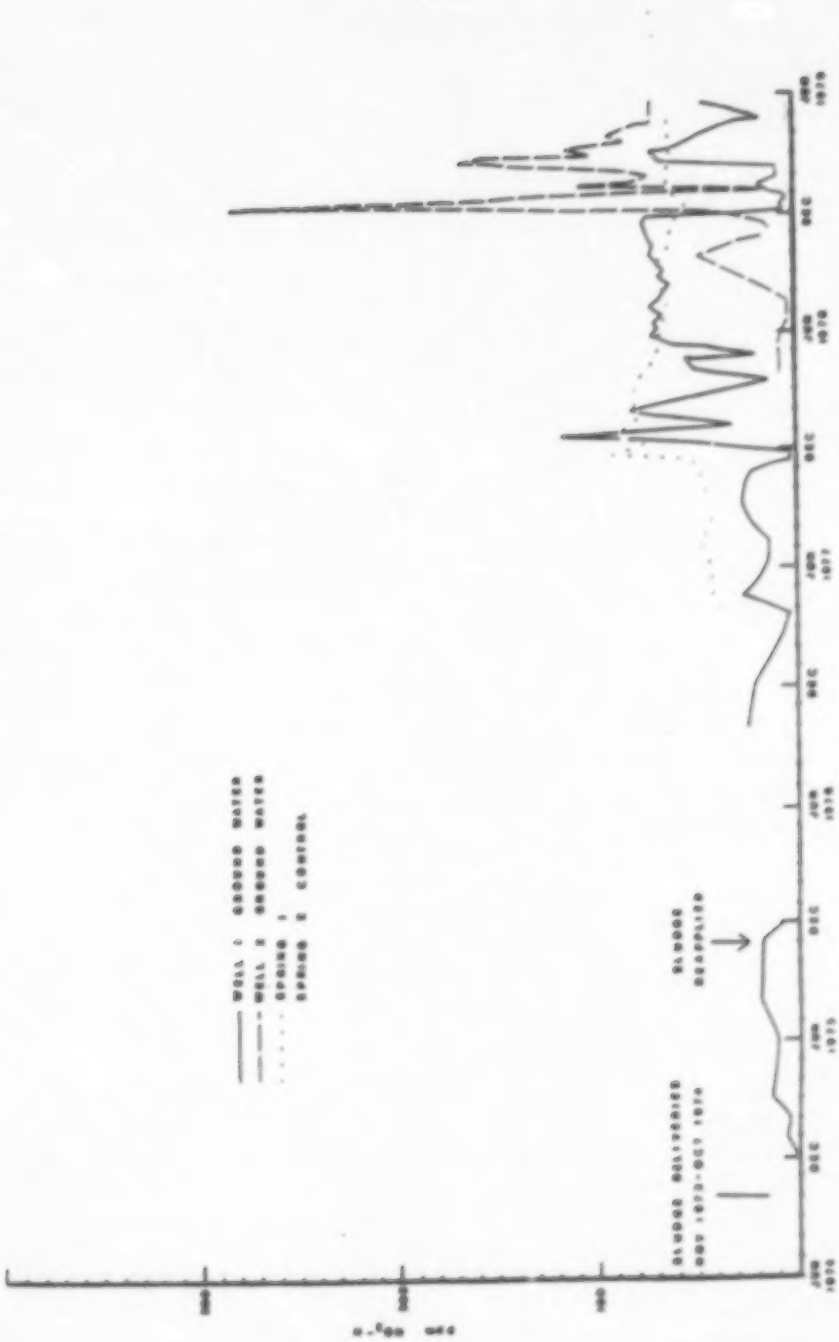


Figure 9 Nitrate concentrations in wells and springs beneath sludge treated areas at Pack Forest. Edmonds & Cole (1980)

A series of techniques have been tested to determine the effectiveness of deer browsing controls, herbicides and mechanical tilling for the control of both rodents and weeds. Mechanical tilling between rows of trees in plantations may be the most effective way to control vegetation and rodents. Deer fencing, big game repellent (BGR) and vexal tubing to protect the tree tops were all tried, however the fencing appeared to be the most effective means of controlling the preferential browsing on sludge-grown trees.

Douglas fir and Sitka spruce had the best conifer seedling height, diameter and biomass response to sludge applications based on studies at Pack Forest and the University of Washington Arboretum. Ponderosa pine in the field appeared to be the most tolerant to weed and rodent competition. Western red cedar had the worst initial survival and growth rate. Both Lombardi poplar cuttings and black cottonwood responded well to sludge applications.

A sludge application vehicle for distributing 20% solids sludge through a "cannon" capable of shooting the sludge up to 125 feet was developed by the University of Washington. The force necessary to throw the sludge this distance did not significantly damage the tree bark. The vehicle has a 3,000 gallon tank which can be discharged within 5 minutes of pumping operation. A truck loading system utilizing a 60-horsepower electrical drive Vaughn pump and a 6-inch delivery system was developed to load the transport vehicle from a sludge lagoon located at Pack Forest. Using this vehicle a total of 2" of a scheduled 4" (20% solids sludge) application has been applied to a series of forested test plots. This amounts to a nitrogen application rate of approximately 2,000 pounds per acre. Most of the test stands were pre-commercially thinned prior to the sludge application. The University is investigating the use of a gravity feed system for the loading of the sludge application vehicle.

The cost of applying sludge to forest soils is significantly higher than those found in plantation management and fertilization practices normally used in forest management. While the initial cost of applying sludge to cleared areas is lower, the overall 5-year plantation management cost is estimated to be $3,000 per acre. The initial cost of pumping sludge into an existing forest stand is considerably higher than direct dumping in clearcut sites, however, the ensuing maintenance costs on clearcuts are avoided. Studies of sludge decomposition rates indicate that the sludge applied to clearcuts undergoes more rapid decomposition than that applied in existing stands of timber. Optimum decomposition appeared to be at the 4" sludge treatments of 1:1 sludge-sawdust mixtures in both cleared and existing forest. Heavier treatments in the forest stands remained anaerobic for longer periods of time. Sawdust additions

enhanced biological activity and decreased nitrate losses, as did the intermediate rye and oat crops. Winter-applied sludge decomposed more rapidly than that applied during summer months due to more favorable decomposition conditions.

Nitrate leaching is the major environmental problem associated with sludge applications to clearcuts and existing forests. The nitrate levels exceeded 10 parts per million in the springs draining a major sludge application site on the Everett gravelly soils. The nitrate levels increased when the sludge was incorporated with soil. Phosphates and heavy metals have not been observed to move a significant distance through the active soil zone. In tests completed to date there has been no significant movement of bacteria or virus into the groundwater. No enterovirus or salmonella bacteria were found in the groundwater beneath the sludge treated areas. Fecal coliform counts were between 1 and 6 million at the time the sludge was applied and approached background levels within one year. Substantial coliform dieoff were noted within 6 months in many cases. The rate of bacterial dieoff is impacted by the site management practices, weather conditions and site vegetation.